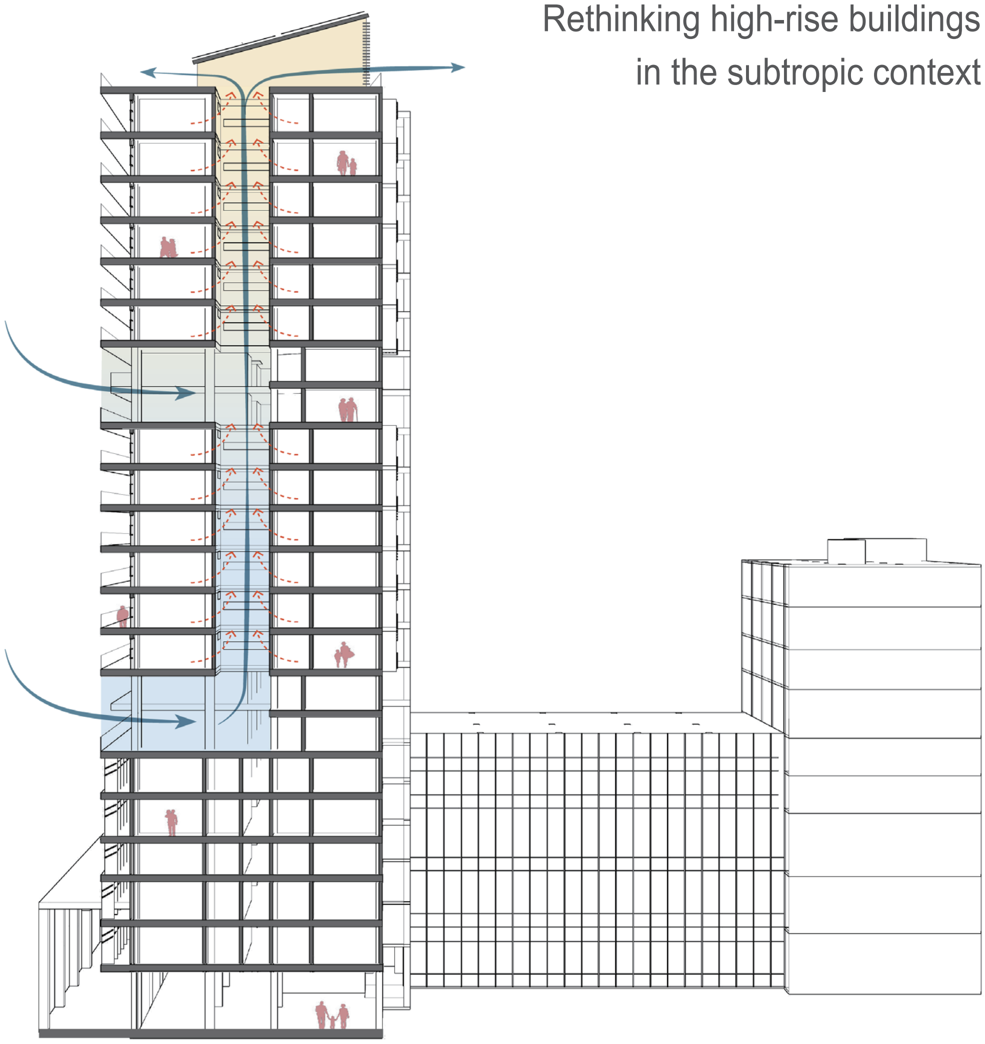
HOW TO MAKE HIGH-RISE BUILDINGS "GREENER" IN LINGNAN REGION OF CHINA

Rethinking high-rise buildings
in the subtropic context



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ABSTRACT

With the increase in high-rise buildings in Lingnan, some early high-rise buildings have exposed problems such as high energy consumption and aging structures, needing to restoration. This thesis aims to get inspiration from traditional Lingnan dwellings to present a sustainable high-rise residential refurbishment proposal.

Carbon emissions from the Chinese building sector were over 48% of overall emissions in 2020, and embodied carbon emissions were approximately equal to operational carbon emissions (Chen Zhu et al., 2023). Increasingly high-rise buildings use high-embodied carbon materials like steel and concrete, which may be a contributing factor. Although wooden skyscrapers have emerged in recent years, their foundations still rely on steel and concrete. HVAC systems in high-rise buildings contribute large amounts of carbon emissions. Urban renewal and demographic changes have resulted in a rise in vacancies among high-rise structures, particularly office buildings.

The thesis mainly focus on the Lingnan region has a high concentration of high-rise buildings. It hopes to get inspiration from the design concepts of Lingnan traditional dwelling to optimize the design of high-rise residential buildings, reducing their reliance on air conditioning and enhancing indoor comfort. It mainly reviews the spatial layout, heat prevention, natural ventilation, and sun shading designs of two traditional Lingnan dwelling typologies: the coutyard house and the bamboo house. It explores how people constructed houses that adapt to the climate in the era before HVAC systems existed.

Using Guangzhou Hotel as a case study, this thesis explores how to retrofit existing high-rise hotel buildings into mixed-use hotel-residential buildings to reduce embodied carbon emissions while meeting the needs of modern urban development. The climatic characteristics of Lingnan were carefully considered during the design process. The actions encompass the re-optimization of building layout and adjusting the openings, and the enhancement of the building envelopes through improved insulation materials and glazing types to reduce cooling load consumption. Furthermore, shading devices are redesigned based on the various orientations of the building to minimize summer solar heat gain and save cooling energy. Post-renovation, the unit can maintain indoor thermal comfort for over 90% of the time without relying on an HVAC system.

Key words: High-rise building, climate-adaptive design, passive cooling, indoor thermal comfort.

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Chapter 0.1

Why high-rise buildings need to be green?

1.0. CLIMATE-NEUTRAL TARGET

1.0.1 The Paris Agreement

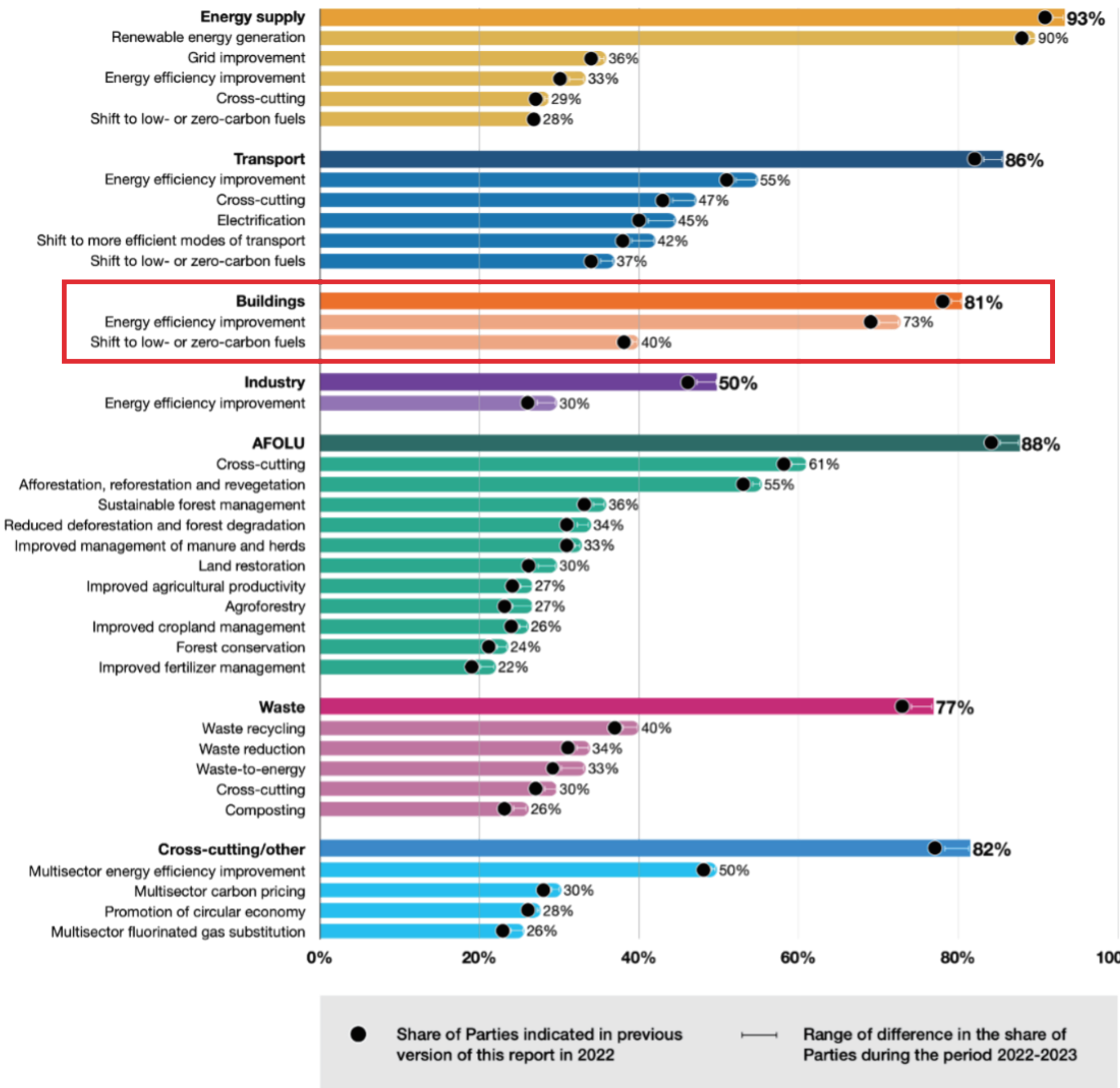
At the United Nations Climate Change Conference (COP21) in Paris in 2015, the Paris Agreement was adopted, therefore signifying a significant turning point in the worldwide reaction to climate change. The pact seeks to hold the global temperature increase to below 2 ℃ above pre-industrial levels and pursue efforts to restrict it to 1.5℃ to lower the hazards presented by climate change; Regularly evaluate the world's collective progress toward this objective; significantly lower greenhouse gas emissions to fight world warming (UN Climate Change, 2023)

The legally binding agreement came into force in 2016 and has 195 parties to it. However, the United States withdrew from the agreement under the Trump administration in 2020, raising concerns about global climate commitments. In 2021, the Biden administration rejoined the agreement by executive order (McGrath, M. 2025). However, with Trump taking office as president again on January 20, 2025 (Clarke, J. 2025), there is still uncertainty as to whether the United States will withdraw from the agreement again.

According to the 2023 Nationally Determined Contributions (NDC) Synthesis Report, 99% of Parties believe that domestic mitigation measures are key to achieving their NDC targets, including energy, transportation, buildings, industry, agriculture and waste management. As shown in Table 1.0, 81% of Parties mentioned the building sector, and 40% focused on improving building energy efficiency and promoting the use of low-carbon or zero-carbon fuels (UN Climate Change, 2023).

Table 1.0 Proportion of parties addressing specified priority regions and commonly cited mitigation strategies in nationally defined contributions.

Source: UN Climate Change



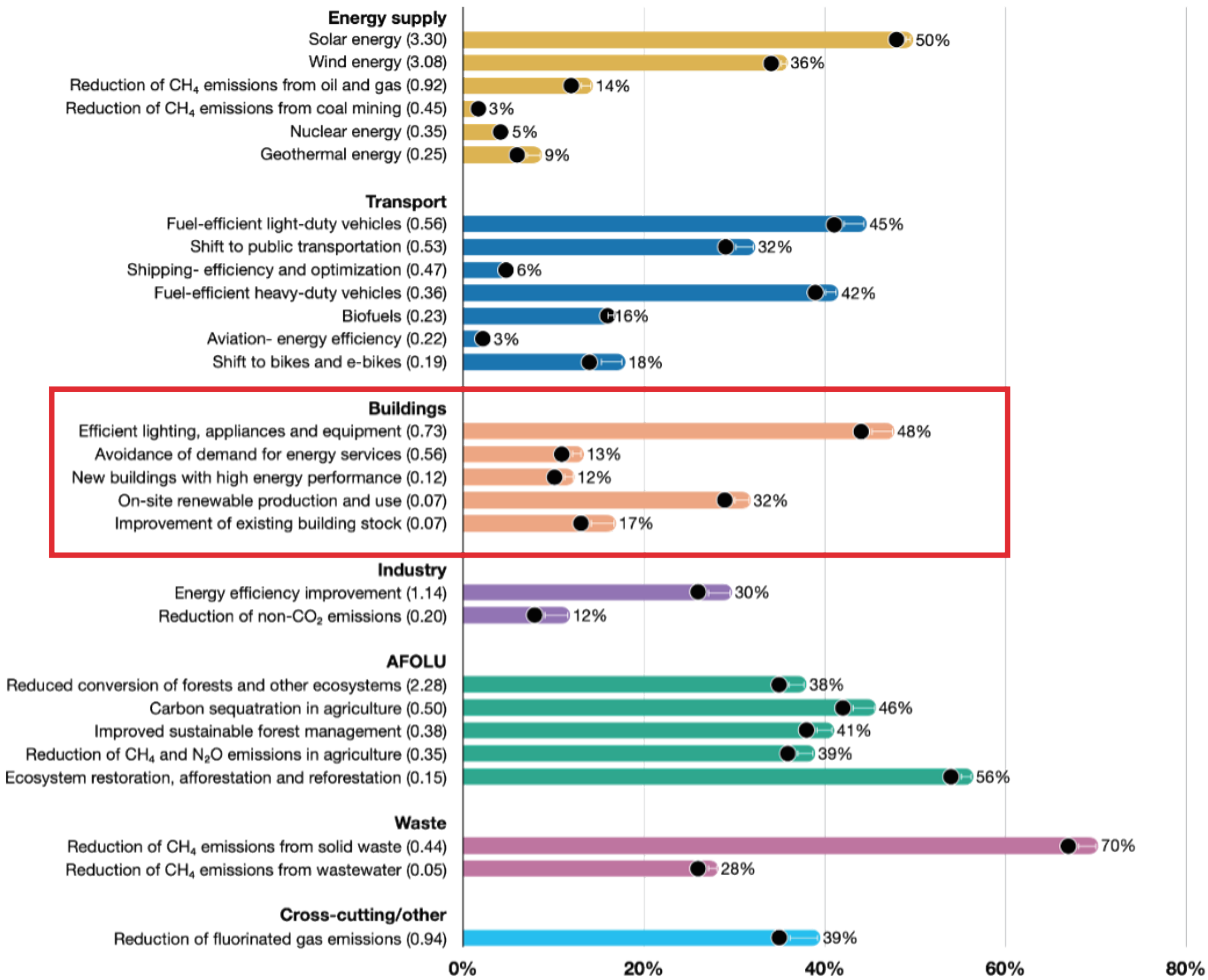
(https://unfccc.int/ndc-synthesis-report-2023#Means-of-implementation)

Parties identified mitigation options in Table 1.1 that cost less than USD 20 per ton of CO2 equivalent. Working Group III's AR6 contribution estimates that these choices will account for almost half of the emission reduction potential needed to reach 1.5 ° C pathways by 2030. Building area mitigation strategies and projected net emission reduction potential (in parenthesis) are listed below: (2023 UN Climate Change)

- **Efficient lighting, appliances, and equipment** (0.73 Gt CO2 eq/year[1]), with 48 % of Parties communicating corresponding measures.
- **On site renewable production and use** (0.07 Gt CO2 eq/year), with 32 % of Parties indicating corresponding measures.
- **Improvement of exiting building stock** (0.07 Gt CO2 eq/year), with 17 % of Parties identifying corresponding measures.
- **Avoidance of demand for energy service** (0.56 Gt CO2 eq/year), with 13% of Parties reporting corresponding measures.
- **New building with high energy performance** (0.12 Gt CO2 eq/year), with 12 % of Parties including corresponding measures.

1 "Gt CO2 eq/year" denotes gigatons of carbon dioxide equivalent per year.

Table 1.1 Share of Parties referring to high-potential mitigation alternatives costing below USD 20 per ton of CO2 equivalent in 2030 in nationally determined contributions.
Source: UN Climate Change



1.0.2 The Chinese target

From the current development of carbon emissions, China's "carbon neutrality" strategy has basically determined a three-step approach. Firstly, to achieve carbon peak by 2030; secondly, to rapidly reduce carbon emissions before 2045; and finally, to **achieve deep decarbonization by 2060,** thus achieving carbon neutrality (Liu, et al., 2022).

The March 2024 "Plan for Accelerating Energy Conservation and Carbon Reduction in the Construction Industry" proposed improving the construction industry's energy conservation and carbon reduction system by 2025 and requiring green principles for all new urban construction projects. The Plan intends to incorporate 20 million square meters of ultra-low and nearly zero energy buildings relative to 2023 (50 million m^2). Current energy-saving activities in buildings will expand by 200 million square meters from the 350 million recorded in 2023. Power consumption will surpass 55%, while urban structures will utilize 8% renewable energy. This should cut carbon emissions and boost building energy economy. (The State Council of the People’s Republic of China.2024).

This work plan also shows 12 important measures. Most of them are similar to the 5 major mitigation options of the building areas shown by the 2023 NDC Synthesis Report. Additionally, based on China's national conditions, the following additional measures have also been taken:

- **Enforce strict management of building demolition while enhancing the renovation, preservation, and utilization of old buildings.** Strengthen supervision and management of building demolition across all regions. All regions must control construction timing and firmly prevent the waste of energy resources resulting from large-scale demolition and construction.

- **Improve carbon emissions calculation methods,** which help to facilitate continuous monitoring of carbon emissions throughout the construction process and standardize accounting standards.

- **Promote the implementation of heat metering and billing system.** Progressively incentivize eligible residential and public buildings to transition towards heat metering and billing system.

Over the past decades, in China, ministerial leadership of climate change as a policy agenda has shifted from the ministry of meteorology, to those of science, development planning, environmental protection and foreign affairs. The overarching rationale of the Chinese approach to climate change is to merge it into the process of economic development, using ongoing industrial progress and energy efficiency China has in place an established, if unique, governance structure for addressing climate change (Daojiong, Z. 2023). As with the other Countries, China is continuing to work on solving climate change.

1.1. THE NUMBER OF HIGH-RISE BUILDINGS IN THE MEGA CITIES OF SOUTHEASTERN CHINA

There is no absolute definition of what constitutes a 'high-rise building;' the definition is subjective and depends on the country context. According to China's "General Code for Civil Building Design" (GB50352-2019)[2] :

- **Residential buildings** with a height greater than **27 meters** and non-single-story **public buildings** with a height greater than **24 meters** but not exceeding 100 meters are classified as **high-rise civil buildings.**
- Buildings with a height greater than **100 meters** are classified as **supertall buildings.**

Based on data from the Council on Tall Buildings and Urban Habitat (CTBUH)[3] , among the top 5 cities by supertall building count in Table 1.2, there are 3 cities from the southeast part of China. **Topping the chart is Hong Kong, followed by Shenzhen (#2) and Guangzhou (#5).** These are the main megacities in the Lingnan region, making it home to over 1,500 skyscrapers. This is inseparable from China's rapid urbanization, economic growth, and ambitious construction projects in recent decades. But in the coming decades, the maintenance of these buildings will become a serious problem.

Table 1.2 Ranked: The Cities with the r
Source: CTBUH

RANK	CITY	COUNTRY
1	Hong Kong	China
2	Shenzhen	China
3	New York City	United Sta
4	Dubai	United Ara
5	Guangzhou	China

(https://www.skyscrapercenter.com/cities)

2 The "General Code for Civil Building Design"(《民用建筑设计通用规范》) is a standard that must be jointly implemented by all parties involved in civil building planning, architectural design, construction, supervision, and acceptance in China.
3 The Council on Tall Buildings and Urban Habitat (CTBUH) is the leading nonprofit for those interested in the future of cities. It examines how urban density and vertical growth can foster sustainable and healthy cities amid mass urbanization and climate change. Key focuses include the relationship between policy, buildings, people, and infrastructure.

number of buildings that are 150 meters and taller in 2023.

	POPULATION	AREA	DENSITY	Number of Buildings 150m+	200m+	300m+
	7,547,652	1,104 M km^2 426 M mi^2	6,837 people per km^2 17,707 people per mi^2	554	97	6
	12,356,820	1,748 M km^2 675 M mi^2	7,069 people per km^2 18,309 people per mi^2	410	161	20
ates	8,804,194	778 M km^2 300 M mi^2	11,316 people per km^2 29,310 people per mi^2	316	98	17
ab Emirates	3,478,300	4,114 M km^2 1,588 M mi^2	845 people per km^2 2,190 people per mi^2	263	127	31
	16,096,724	3,843 M km^2 1,484 M mi^2	4,189 people per km^2 10,848 people per mi^2	191	58	11

1.2. THE MAIN PROBLEMS OF THE HIGH RISE BUILDING

1.2.1 Ecological problem of high-rise building

In the past, structural tragedies generated worries about high-rise building safety. The September 11, 2001, terrorist assaults on the World Trade Center exposed high-rise building vulnerabilities such active and passive fire prevention system failure, structural redundancy, and egress system performance. These findings suggested code changes. However, skyscrapers recently have been criticized for their environmental impact. These buildings use a lot of energy, electricity, water, and materials, making their ecological footprint significant although the skyscrapers can slow down urban expansion and infrastructure construction to a certain extent.

In 2020, when both embodied and operational carbon are taken into account, China's building sector was responsible for 4.36 billion tCO_2—amounting to 48.0% of the country's total energy-related carbon emissions (Figure 1.3). Of that total, operational carbon emissions contributed 2.07 billion tCO_2(47.6%), while embodied carbon emissions in buildings added up to 2.28 billion tCO_2 (52.4%). **Notably, the proportion of embodied carbon in the building sector has been on the rise; since 2010, embodied carbon has consistently made up between 50% and 56% of the sector's total emissions, effectively matching the operational carbon emissions** (Chen Zhu et al., 2023).

Studies on embodied carbon emissions in China's building sector from 2015 to 2020 estimate that the total embodied carbon emissions of China's building sector in 2020 were 2.10 billion tCO2, or roughly 23.1% of China's total energy-related carbon emissions (Chen Zhu et al., 2023). As illustrated in Figure 1.4, the indirect material production and transportation embodied carbon emissions accounted for 1.97 billion tCO2, or 93.8% of the total. **Among these, steel, cement, and aluminum are the most dominant emission contributors, representing 92.7% of the total building embodied carbon emissions.** Although there are cases of using timber to build high-rise buildings, it is currently not possible to avoid the environmental impact entirely. The foundation of buildings still requires steel bars and concrete, and no alternative material can yet replace these.

Figure 1.3 Embodied and operational carbon emissions of China's building sector (2005–2020).
Source: Chen Zhu, et.al.2023

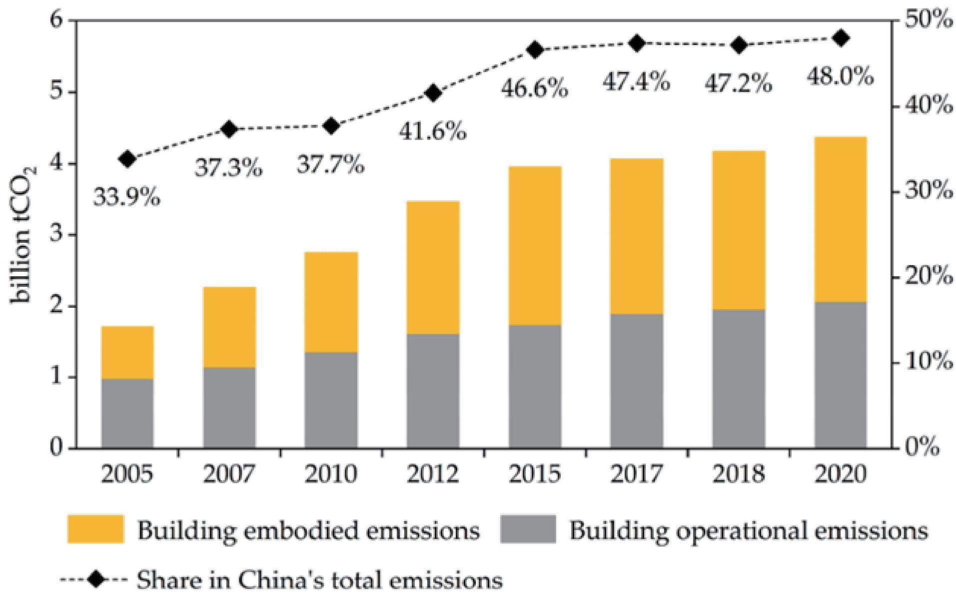
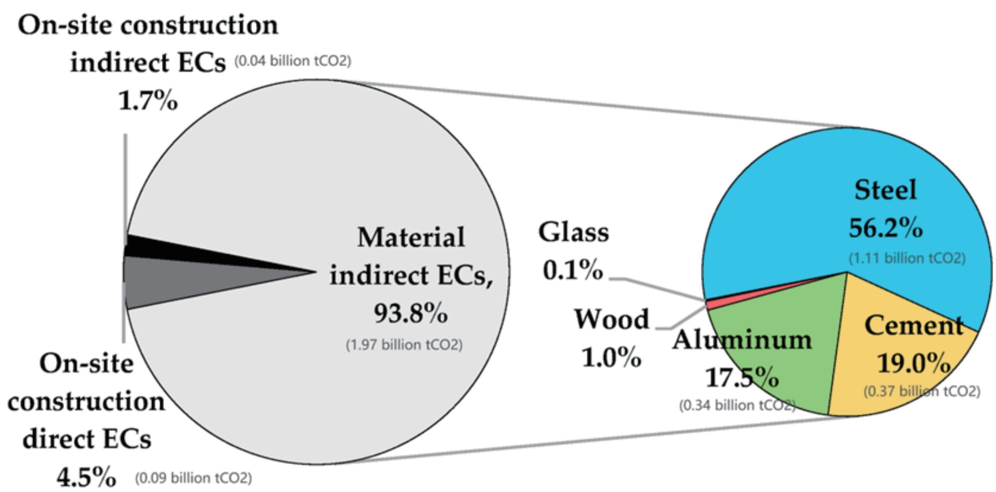


Figure 1.4 The composition of China's building embodied carbon emissions and the composition of indirect material embodied carbon emissions (2020).
Source: Chen Zhu, et.al. 2023



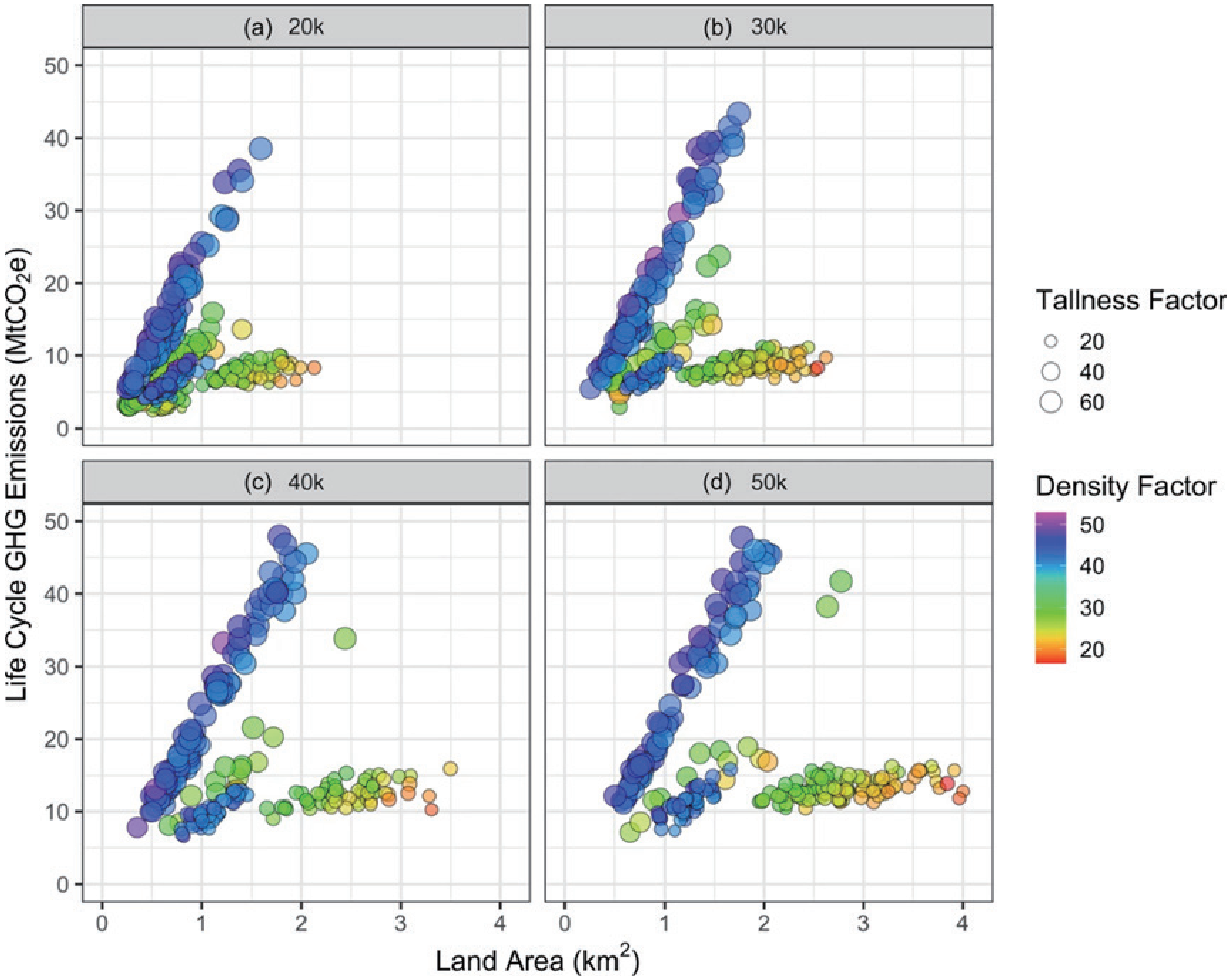
1.2.2 The restriction of high rise building in China

In recent year, the early urban design theories claimed that 'higher and denser buildings can save land and be more environmentally friendly' have not been proven correct. **The reason for this is that urban environment design frequently concentrates on minimizing the operational energy demand and the carbon emissions associated with the energy used during the opertaion period, while neglecting life cycle GHC emissions** (Dario Trabucco. et al. 2016). Based on a research in npj[4] Urban Sustainability in 2021. The researchers used a method that decouples density and tallness in urban environments, allowing each to be analyzed individually. However, it is worth noting that in this mothod, in the life cycle assessment of the building component setting of the model only considers the core structure, building facades and roof, but does not include foundations and surrounding infrastructure(Francesco Pomponi. et al. 2021). The service life of each building type is assumed to be 60 years, after which the building will be demolished and the materials will be sent to landfill (Francesco Pomponi. et al. 2021).

This approach was tested in midtown Manhattan, which has high density and height ratios (HDHR), and downtown Paris, which has HDLR. The "Radiant City" design by Le Corbusier represents low-density, high-rise (LDHR) habitats, while suburban sprawl is LDLR. As shown by the enormous bubbles in Figure. 1.5, high-rise buildings emit more life cycle greenhouse gases than low-rise buildings. Thus, when population remains constant, higher buildings significantly affect life cycle greenhouse gas emissions in metropolitan areas. For 20,000 people, switching from an HDLR (little purple bubbles) to an HDHR (large purple bubbles) typology increases life cycle greenhouse gas emissions by 140%; for 30,000, 40,000, and 50,000, the increases are 154%, 143%, and 132%, respectively. This shows that higher structures have a greater impact than denser ones (Francesco Pomponi et al. 2021). **High-density low-rise cities like Paris are more carbon-efficient than New York.These findings disprove the idea that higher buildings are the best way to meet urban space demand. They show that denser urban areas use less land and do not significantly increase life cycle GHG emissions.**

4 npj Urban Sustainability is an open-access, online-only journal that publishes inter- and cross-disciplinary research on the reshaping and re-shaping of cities to address significant economic, social, and environmental challenges. This research includes the increasing role of digital tools and big data in this process.

Figure 1.5 Life cycle GHG emissions versus built land area for fixed populations.
Source: Pomponi, F. et al., 2021



Results presented for 20 (a), 30 (b), 40 (c), and 50 (d) thousand people.

From this point of view, it is unwise to continue constructing such energy-intensive and environmentally unfriendly buildings. **Retrofitting existing skyscrapers represents the preferred approach for the future of skyscraper design.** In 2020, The Chinese government had introduced new requirements for the height and design of skyscrapers. **The height restrictions were tightened: new projects over 500 meters were completely banned, and those over 250 meters were severely limited.** The construction of 150-meter-high skyscrapers in cities with a population of less than 3 million has just been prohibited (State Council of the People’s Republic of China, 2021).

1.2.3 The building vacancy rate in China

Given China's extensive stock of high-rise buildings, the country is adopting strategies to address vacancies and support economic revitalization. Many high-rise buildings now stand vacant due to urban renewal, population shifts, policy changes, and market dynamics. Predominantly commercial, these buildings have led to an oversupply in office markets. Based on a 2024 Oxford Economics analysis given in Table 1.6, major C**hinese cities have office vacancy rates above 20%; almost half of them exceed 30%, the most worldwide.** The fast rate of urbanization and development exceeding demand help to explain some of this notable excess (Nicholas Wilson, 2024).

For the residential building, as shown in Figure 1.7, the housing vacancy rate in the China's first tier cities[5] in 2018 is between 15% and 17%, except Beijing, representing 19.8% (Zhiru Tan, et al.2020). Although all of them have already exceeded the upper limit of the natural vacancy rate 5%[6] . Despite this, **the housing vacancy rate in first-tier cities remains lower than that for office buildings.**

Now China has the important task of using these tall skyscrapers to guarantee economic sustainability. **Among the strategies are retrofitting buildings for new use, such mixed-use developments or residential units from office spaces.** In line with more general sustainability objectives, also efforts are being undertaken to raise the environmental performance and energy efficiency of these buildings.

5 There are four cities belong to first tier cities: Beijing, Shanghai, Guangzhou, and Shenzhen.

6 Vacancy rates that greatly exceed 5% this critical value are indicative of low market conditions and low land-use efficiency.

Table 1.6 Office vacancy rates 2024, China vs select global cities.

Source: Oxford Economics/various broker reports

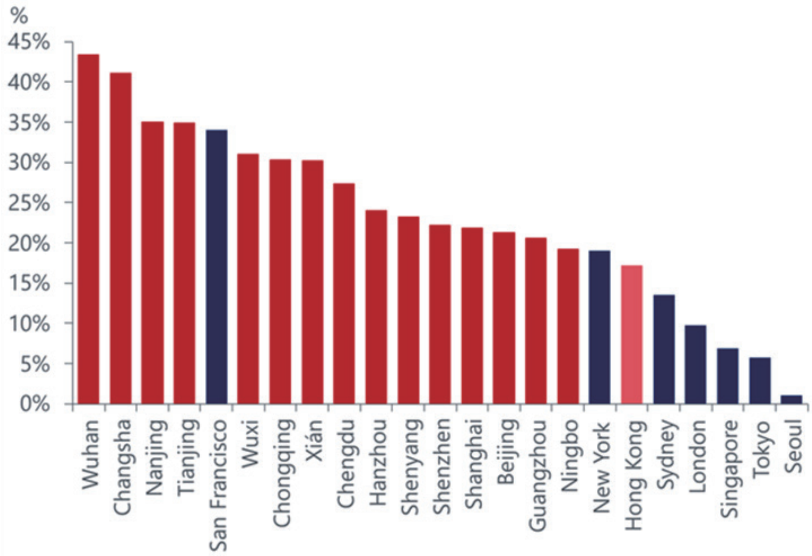


Figure 1.7 Housing vacancy rates in major cities in China in 2018.

Source: Langeist, 2021

Chapter 0.2

How to reduce the carbon footprint of high-rise buildings in Lingnan region?

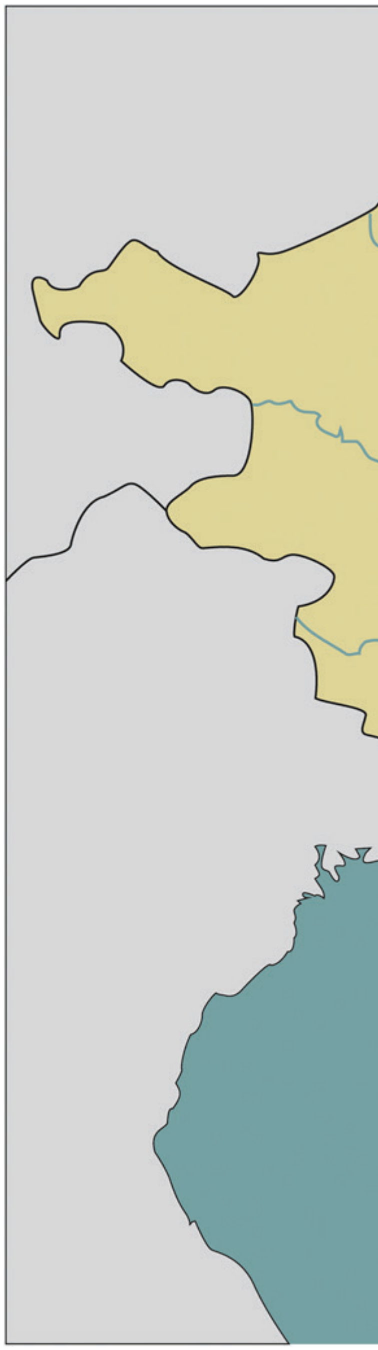
2.0. THE CLIMATE CHARACTERISTICS OF LINGNAN REGION

2.0.1 Where is Lingnan region

Lingnan is a geographical area comprising the modern Chinese areas of Guangdong, Guangxi, Hainan, Hong Kong, and Macau south of the Nanling Mountains[1] (Figure 2.0),Historically, the Baiyue[2] people lived in this region and the center of the old kingdom of Nanyue[3] . The Chinese court saw Lingnan in ancient times as a far-off, tropical, barbaric territory cut off from Zhongyuan, the center of Chinese culture. Consequently, Lingnan culture differs from the conventional Zhongyuan culture in that it is highly flexible, commercial oriented, and pragmatic (Wikipedia authors, 2024).

Figure 2.0 Map of the Lingnan

Source: Nina Demandt, 2019;



1 As the boundary between the south and central subtropical zones, the Nanling (Chinese: 南岭), also called the Wuling (Chinese: 五岭), is a significant mountain range in Southern China that divides the Yangtze Valley from the Pearl River Basin (Wikipedia contributors,2024).

2 During the first millennium BC and the first millennium AD, a number of ethnic groups, including the Baiyue, Hundred Yue, and simply Yue, lived in parts of Southern China and Northern Vietnam (Wikipedia contributors, 2025).

3 The Chinese general Zhao Tuo established Nanyue, also known as Nam Viet in Vietnamese, an ancient kingdom whose family—known as the Trieu dynasty in Vietnamese—ruled until 111 BC (Wikipedia contributors, 2025).

n region.

scale in km

2.0.2 Thermal design zoning for the Lingnan region

According to the Chinese standard for thermal design in civil buildings (GB 50176-2016), the Lingnan region typically falls into the Hot Summer, Warm Winter Zone 4 and the Hot Summer, Cold Winter Zone 3. However, cities with a large number of high-rise buildings, such as Guangzhou, Shenzhen, and Hong Kong, are **classified within the Hot Summer, Warm Winter Zone 4.** In this zone, the focus is primarily on meeting the requirements for heat prevention during summer, while insulation for winter is generally not considered.

Taking Guangzhou as an example, based on its HDD[4] and CDD[5] values (Table 2.0), it falls under the **4B zone in the secondary zoning classification**. In this region, the priority should be on **meeting heat prevention design standards, while insulation may not be necessary. Emphasis is placed on natural ventilation and sun-shading design.**

Table 2.0 Meteorological da
Source: GB 50176-2016(Co

城镇	省份
广州	广东

Town/City	Province
GuangZhou	GuangDon

4 HDD stands for Heating Degree Days.
5 CDD stands for Cooling Degree Days.

ata of Guangzhou

de for thermal design of civil buildings in China), Page 68

气候区属	气象站			最冷月平均温度 $t_{min \cdot m}$ (℃)	最热月平均温度 $t_{max \cdot m}$ (℃)	采暖度日数 $HDD18$ (℃·d)	空调度日数 $CDD26$ (℃·d)	采暖室外计算温度 t_w (℃)	累年最低日平均温度 $t_{e \cdot min}$ (℃)
	东经 (°)	北纬 (°)	海拔 (m)						
4B	113.33	23.17	41	14.3	28.8	373	313	8.3	−0.5

	Climatic Zone	Meteorological Station			Multi-year Average Temperature in January $t_{min \cdot m}$ (℃)	Multi-year Average Temperature in July $t_{max \cdot m}$ (℃)	Heating Degree Days (base temperature of 18°C) $HDD18$ (℃·d)	Cooling Degree Days (base temperature of 26°C) $CDD26$ (℃·d)	Outdoor Design Temperature for Heating t_w (℃)	Multi-year Lowest Daily Average Temperature $t_{e \cdot min}$ (℃)
		East Longitude (°)	North Latitude (°)	Altitude (m)						
g	4B	113.33	23.17	41	14.3	28.8	373	313	8.3	−0.5

Table 2.1 First-level zoning index and design principles for building thermal design
Source: GB 50176-2016(Code for thermal design of civil buildings in China), Page 17

一级区划名称	区划指标		设计原则
	主要指标	辅助指标	
严寒地区（1）	$t_{min \cdot m} \leqslant -10℃$	$145 \leqslant d_{\leqslant 5}$	必须充分满足冬季保温要求，一般可以不考虑夏季防热
寒冷地区（2）	$-10℃ < t_{min \cdot m} \leqslant 0℃$	$90 \leqslant d_{\leqslant 5} < 145$	应满足冬季保温要求，部分地区兼顾夏季防热
夏热冬冷地区（3）	$0℃ < t_{min \cdot m} \leqslant 10℃$ $25℃ < t_{max \cdot m} \leqslant 30℃$	$0 \leqslant d_{\leqslant 5} < 90$ $40 \leqslant d_{\geqslant 25} < 110$	必须满足夏季防热要求，适当兼顾冬季保温
夏热冬暖地区（4）	$10℃ < t_{min \cdot m}$ $25℃ < t_{max \cdot m} \leqslant 29℃$	$100 \leqslant d_{\geqslant 25} < 200$	必须充分满足夏季防热要求，一般可不考虑冬季保温
温和地区（5）	$0℃ < t_{min \cdot m} \leqslant 13℃$ $18℃ < t_{max \cdot m} \leqslant 25℃$	$0 \leqslant d_{\leqslant 5} < 90$	部分地区应考虑冬季保温，一般可不考虑夏季防热

Primary Zone Classification	Zone Indicators		Design Principles
	Primary Indicator	Secondary Indicator	
Severe Cold Zone (1)	$t_{min \cdot m} \leqslant -10℃$	$145 \leqslant d_{\leqslant 5}$	Must fully meet winter insulation requirements; generally, summer heat prevention is not considered.
Cold Zone (2)	$-10℃ < t_{min \cdot m} \leqslant 0℃$	$90 \leqslant d_{\leqslant 5} < 145$	Must meet winter insulation requirements; in some areas, summer heat prevention is also considered.
Hot Summer, Cold Winter Zone (3)	$0℃ < t_{min \cdot m} \leqslant 10℃$ $25℃ < t_{max \cdot m} \leqslant 30℃$	$0 \leqslant d_{\leqslant 5} < 90$ $40 \leqslant d_{\geqslant 25} < 110$	Must meet summer heat prevention requirements and appropriately consider winter insulation.
Hot Summer, Warm Winter Zone (4)	$10℃ < t_{min \cdot m}$ $25℃ < t_{max \cdot m} \leqslant 29℃$	$100 \leqslant d_{\geqslant 25} < 200$	Must fully meet summer heat prevention requirements; generally, winter insulation is not considered.
Mild Zone (5)	$0℃ < t_{min \cdot m} \leqslant 13℃$ $18℃ < t_{max \cdot m} \leqslant 25℃$	$0 \leqslant d_{\leqslant 5} < 90$	Some areas should consider winter insulation; generally, summer heat prevention is not considered.

Table 2.2 Secondary zoning indicators and design requirements for building thermal engineering design.

Source: GB 50176-2016(Code for thermal design of civil buildings in China), Page 18

Secondary Zone Classification	Zone Indicators		Design Requirements
Severe Cold Zone A (1A)	$6000 \leq HDD18$		Winter insulation requirements are very strict. Must meet insulation design standards, and heat prevention design is not considered.
Severe Cold Zone B (1B)	$5000 \leq HDD18 < 6000$		Winter insulation requirements are strict. Must meet insulation design standards, and heat prevention design is not considered.
Severe Cold Zone C (1C)	$3800 \leq HDD18 < 5000$		Must meet insulation design standards, heat prevention design may not be considered.
Cold Zone A (2A)	$2000 \leq HDD18 < 3800$	$CDD26 \leq 90$	Should meet insulation design standards, heat prevention design may not be considered.
Cold Zone B (2B)		$CDD26 > 90$	Should meet insulation design standards, should meet heat prevention design standards, consider natural ventilation, and sun-shading design.
Hot Summer, Cold Winter Zone A (3A)	$1200 \leq HDD18 < 2000$		Should meet both insulation and heat prevention design standards, and prioritize natural ventilation and sun-shading design.
Hot Summer, Cold Winter Zone B (3B)	$700 \leq HDD18 < 1200$		Should meet both insulation and heat prevention design standards, and prioritize natural ventilation and sun-shading design.
Hot Summer, Warm Winter Zone A (4A)	$500 \leq HDD18 < 700$		Should meet heat prevention design standards and meet insulation design standards, emphasize natural ventilation, and sun-shading design.
Hot Summer, Warm Winter Zone B (4B)	$HDD18 < 500$		Should meet heat prevention design standards, insulation design may not be considered, emphasize natural ventilation and sun-shading design.
Mild Zone A (5A)	$CDD26 < 10$	$700 \leq HDD18 < 2000$	Should meet winter insulation design standards, heat prevention design may not be considered.
Mild Zone B (5B)		$HDD18 < 700$	Must meet winter insulation design standards, heat prevention design is not considered.

2.1. PASSIVE DESIGN APPROACHES AND THE CASE STUDIES OF TRADITIONAL LINGNAN DWELLINGS

2.1.1 Heat prevention design

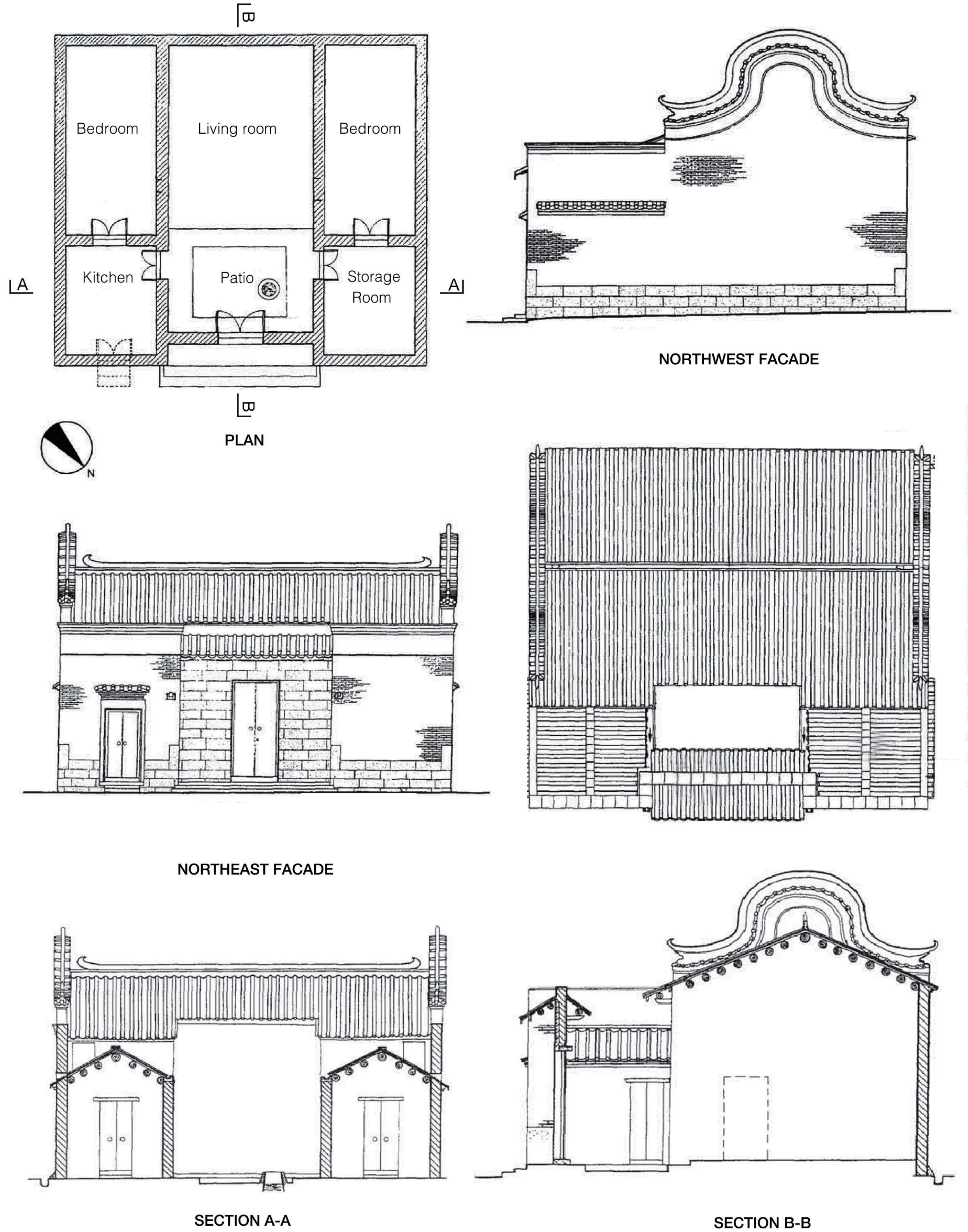
Located in the Hot Summer, Warm Winter Zone B, the Lingnan area receives strong solar radiation all year long coupled with extended periods of high temperatures and high humidity(80-90%). Buildings thus have to solve the long summer season's heat protection problem. Heat primarily enters buildings through three mechanisms: radiation, conduction, and convection. As a result, architectural insulation strategies are divided into radiant insulation, conductive insulation, and convective insulation. In the Lingnan region, since the temperature difference between the interior and exterior is relatively small, radiant and conductive insulation are the most applied methods.

In traditional Lingnan architecture (Figure 2.1), **the most common residential designs typically adopt a strategy of being closed to the outside and open to the inside.** As Figure 2.2 shown, Exterior walls generally have no windows or only small ones, with windows mainly facing inward toward a central courtyard to reduce the effects of solar radiation. The walls are often constructed using cavity walls (Figure 2.3) or oyster shell walls (Figure 2.4) to improve the thermal insulation of the building’s exterior.

Figure 2.1 Images of Traditional Villages in Lingnan during the Ming and Qing Dynasties.
Source: Guangdong Provincial Government Information Office. 2020.

Figure 2.2 Drawings of Traditional Dwelling in Lingnan

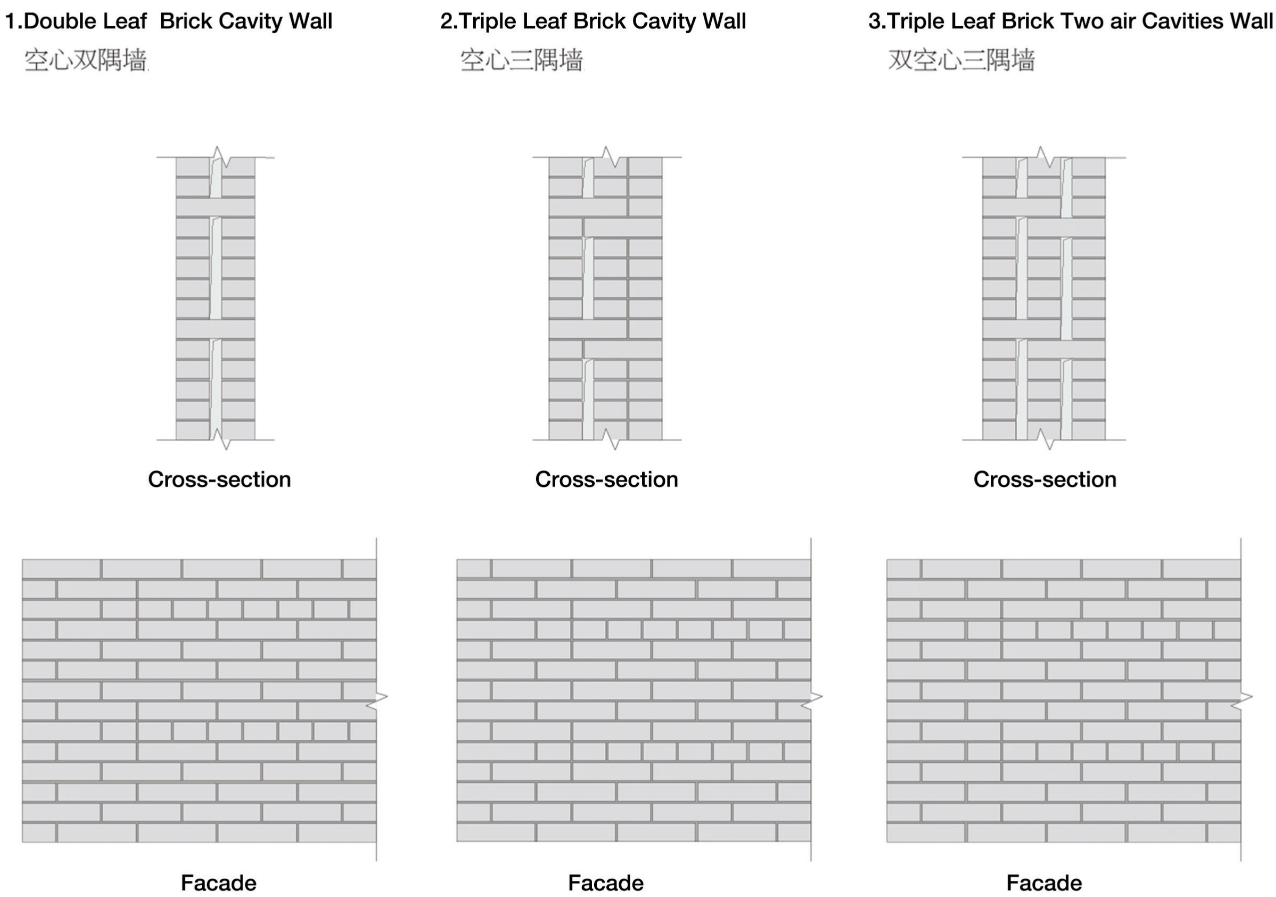
Source: Tang Guohua, 2000; "Selected Measure Drawings of Guangzhou Historical buildings", Page 136



A cavity wall, as illustrated in the Figure 2.3, is composed of two or more layers (or "leaves") of brickwork with an empty air cavity between them. The air-filled cavity serves as a thermal barrier, diminishing heat transfer between the building's outside and interior. This design traps air, a poor thermal conductor, therefore impeding heat flow over the wall.

The average specific heat capacity is roughly 2.262 MJ/m^3·k (Wang Shuo, 2022), while the average thermal conductivity of oyster shells is 0.400 W/m·k. This shows that oyster shell wall (Figure 2.4) structures provide excellent thermal insulation, which could be comparable to the external insulation performance of a 30mm thick EPS (expanded polystyrene) panel (Wang Shuo, 2022). Because of this, oyster shell walls are very good at slowing down heat movement, which helps keep the temperature inside more stable.

Figure 2.3 Common Types of Cavity Walls in Lingnan Residential House
Source: Repair Drawings of Historical Buildings in Guangzhou, Page 42



https://www.gz.gov.cn/GZ15/2.2/201806/6b7a424f20b44cdfb2ba7f7d866d3932/files/e7c061d4e93242f5b8b1731377ae6132.pdf

Figure 2.4 Oyster shell wall building in Shawan Ancient Town, Guangzhou
Source: Mu Qiancheng, 2021

2.1.2 Sun shading design

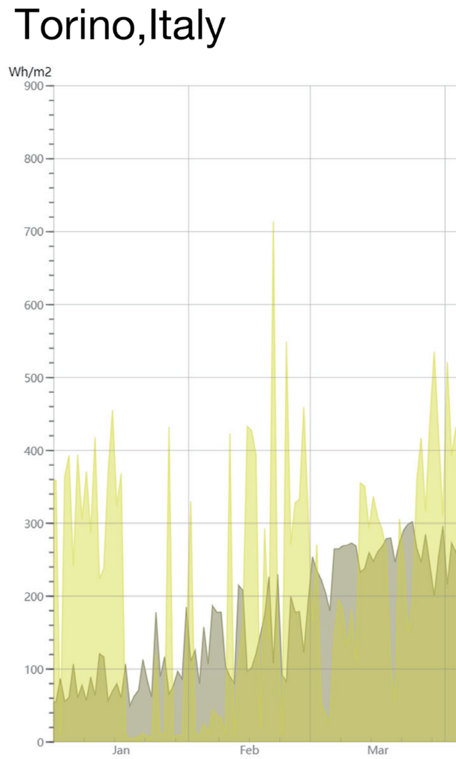
According to the design principles of hot summer and warm winter zone B from Table 2.2, emphasizing sun shading design is crucial. However, it is important to note that due to the influence of oceanic air masses and tropical cyclones during **the summer months in the Lingnan region, the local climate is characterized by frequent cloudy and rainy conditions,** as well as extreme weather events like typhoons. These factors significantly impact the region's solar radiation patterns.

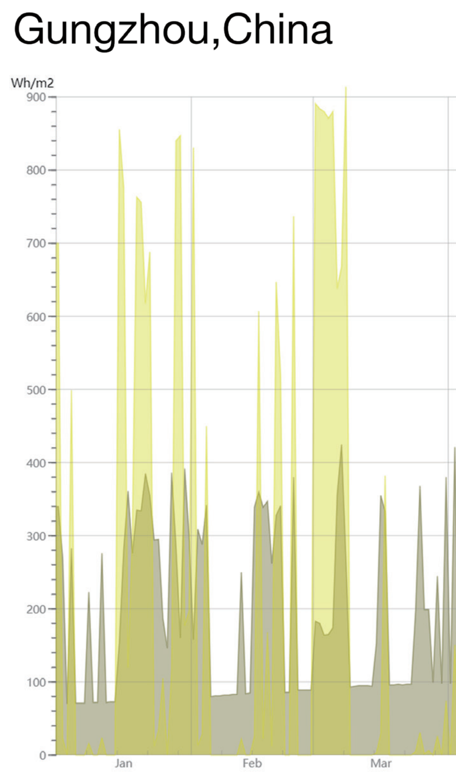
During the spring and summer, Guangzhou gets more diffuse solar energy than Turin, Italy (Figure 2.5). **It is harder for traditional fixed shading designs to control diffuse radiation because it comes from more than one direction, which are good at blocking direct solar radiation.** Another issue is that, if not designed properly, fixed shading devices would also block the direct sunlight during the winter, which is necessary to heat the indoor space.

Figure 2.5 Comparison of Direct and

Source: Created by the author, 2024

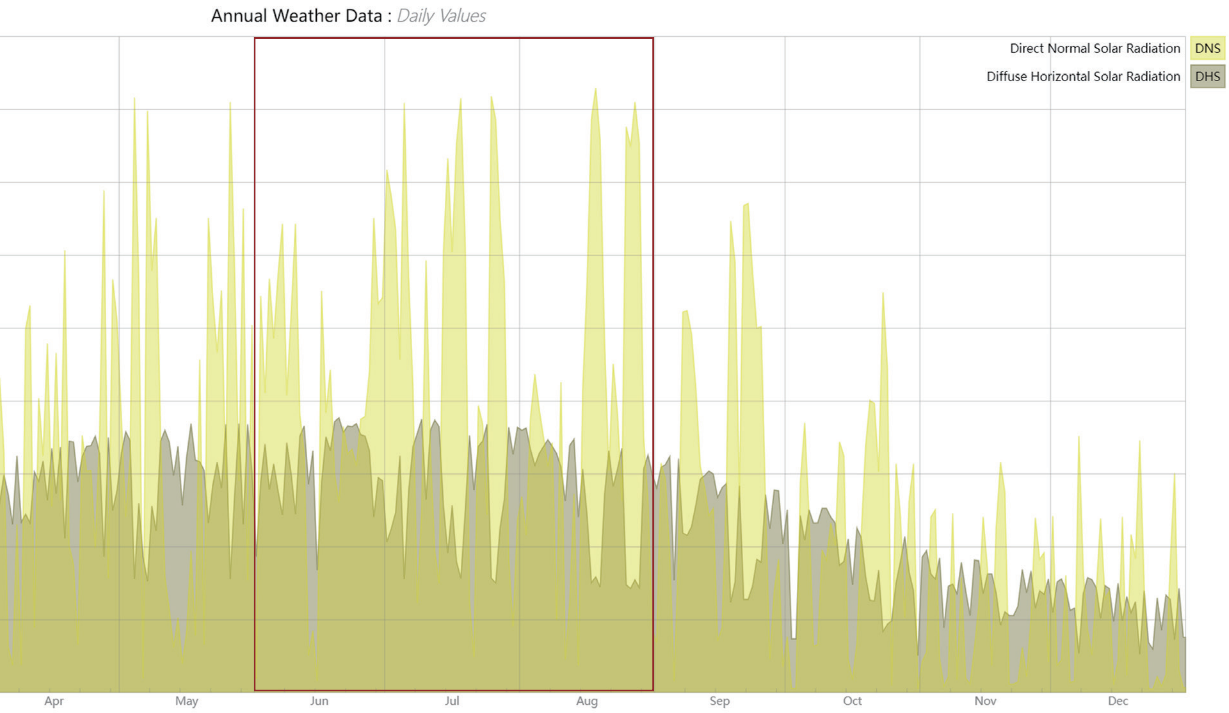
Tool:https://drajmarsh.bitbucket.io/d

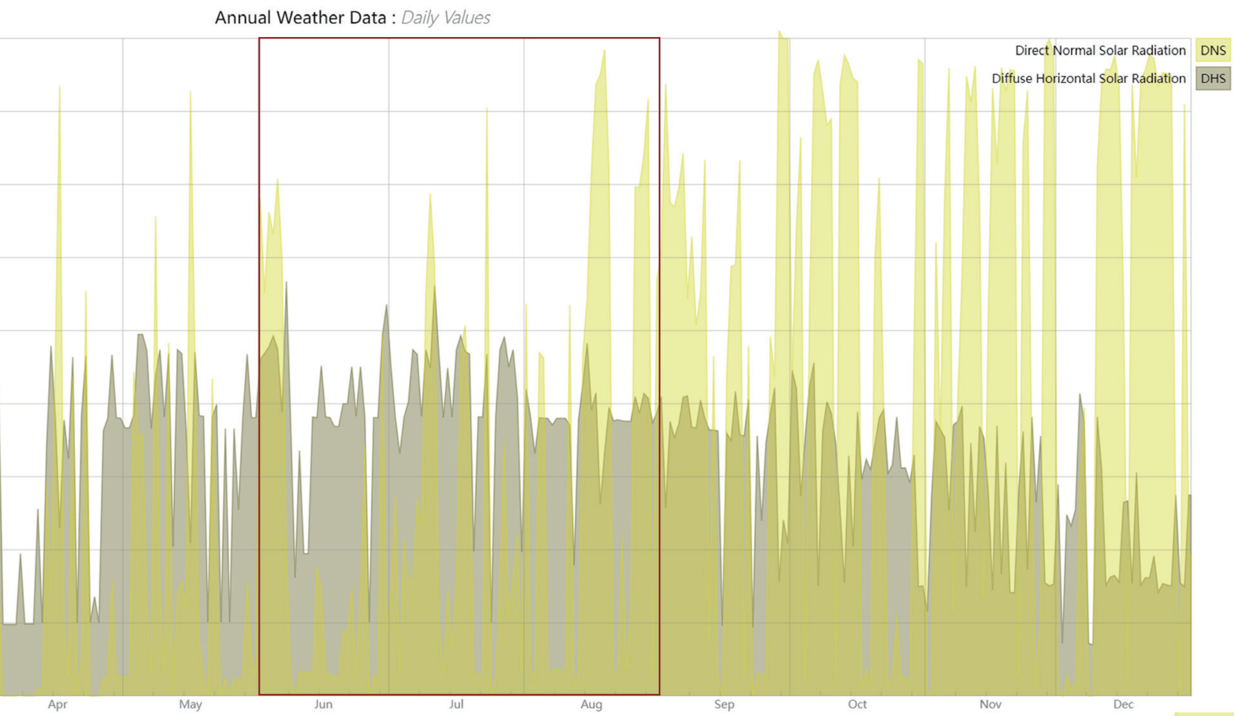




d Diffuse solar radiation between Guangzhou and Turin

lata-view2d.html





Direct Normal Solar Radiation DNS

Diffuse Horizontal Solar Radiation DHS

Summer Months

Table 2.3 Monthly meteorological data of Guangzhou from 1981 to 2021.
Source: weather.cma.cn, 2023

Months	January	February	March	April	Ma
Average temperature °C	13.8	14.1	18.3	22.3	26.
Maximum temperature °C	24.6	22.7	29.7	28.2	32.
Minimum temperature °C	6.1	4.7	11.3	17.1	19.
Rainfall (mm)	40.9	69.4	84.7	201.2	283
Number of days of rainfall	7.5	11.2	15.0	16.3	18.
Average wind speed (m/s)	2.58	3.26	2.54	2.63	2.1
Average daily solar radiation (kWh/m^2)	3252	2614	2279	2834	407

y	June	July	August	September	October	November	December
0	27.1	28.8	28.0	27.3	24.3	20.0	15.3
8	32.9	34.7	34.6	34.9	32.3	28.9	24.2
4	22.6	22.0	24.0	22.5	18.6	13.0	8.6
.7	276.2	232.5	227.0	166.2	87.3	35.4	31.6
3	18.2	15.9	16.8	12.5	7.1	5.5	4.9
4	2.67	2.51	2.25	1.94	3.22	2.57	3.79
70	3676	4541	4692	4676	5092	4745	4361

Looking back at the history of Lingnan architecture, we often mistakenly assume that the wide eaves and deep verandas seen in traditional Lingnan buildings of the Ming and Qing dynasties (from 1368 to 1912), as well as arcades (骑 楼)[6] , which became popular in the 1980s, were primarily designed for sun shading. However, meteorological analysis of the Lingnan region—using Guangzhou as an example (Table 2.3)—shows that more than half of the days in the typical summer months are rainy. Therefore, **the main function of them was likely rain protection rather than sun shading.**

In most traditional Lingnan buildings, the structure is made of timber, and the roof design of the wide eaves can prevent the timber from dacaying by rain (Figure 2.6). Although the arcade developed into a brick and timber structure later, but the ground floor of the building still adopts a recessed design to form a semi-open space that can provide shade on sunny days and shelter from rain on rainy days. It is similar to the porticoes of Turin, Italy (Figure 2.7).,

6 The arcade building (骑楼) is a traditional architectural style in southern China, particularly in Lingnan.

Figure 2.6 The Perspectival Section of Traditional Architecture of Lingnan in Ming and Qing dynasties
Source: Repair Drawings of Historical Buildings in Guangzhou, Page 97

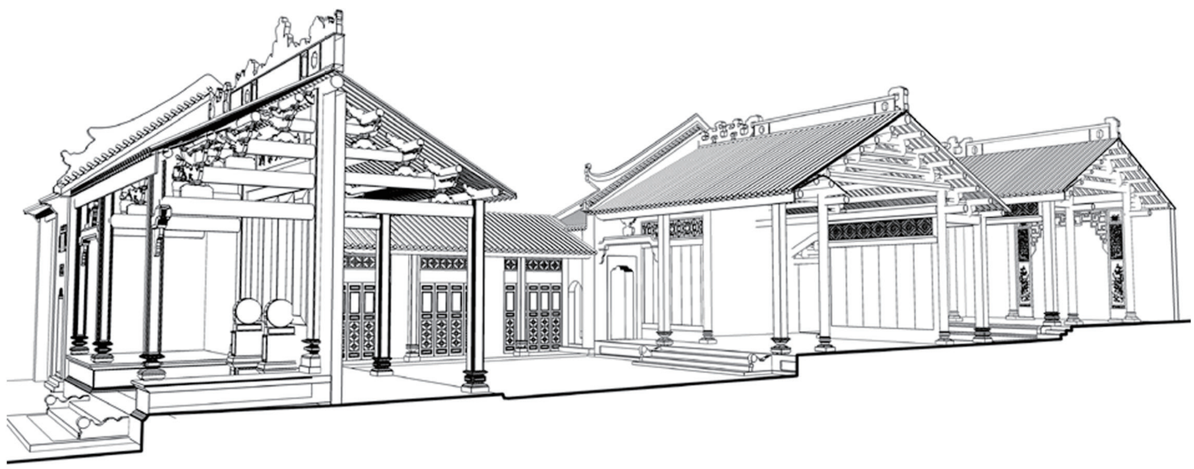


Figure 2.7 Porticoes of Turin and Arcade building (骑楼) of Guangzhou
Source: Fotografia Studio fotografico Gonella, 2014; Livin 广州 , 2020

Turin, Italy

https://www.museotorino.it/view/s/ca16bee2be9d4d6b984b39919adaeab6

Guangzhou, China

https://igz.gzwxb.gov.cn/context/context/200430

Starting in 1952, Xia Changshi[7], a pioneer in modern Lingnan architectural design, **conducted in-depth research on roof shading and window shading.** He implemented numerous shading design techniques in the campuses of Zhongshan Medical College and South China University of Technology. For example, in the laboratory design at Zhongshan Medical College, **he employed a composite shading system with overhand and vertical fins in the south façade of the building** (Figure 2.8.a). In the design of the teaching building for pharmacy at Zhongshan Medical College, he used **double horizontal shading panels**, with the upper and lower overhands extending at different widths, meeting the shading needs for specific time periods (Figure 2.8.b). In the outpatient department at Zhongshan Medical College, he used **wooden louvered shading panels**, with louver sections shaped like diamonds to accelerate air circulation at the top of the windowsill (Figure 2.8.c). In his exploration of roof shading and insulation, he experimented with replacing the flat roofs commonly used in modern architecture with **a hyperbolic arch roof** (Figure 2.8.d). This method helped avoid perpendicular solar rays before and after noon and reduced heat accumulation[8]. Additionally, the openings on both sides of the arch created a curved ventilation path, promoting airflow and heat dissipation. (Xia Changshi, 1958)

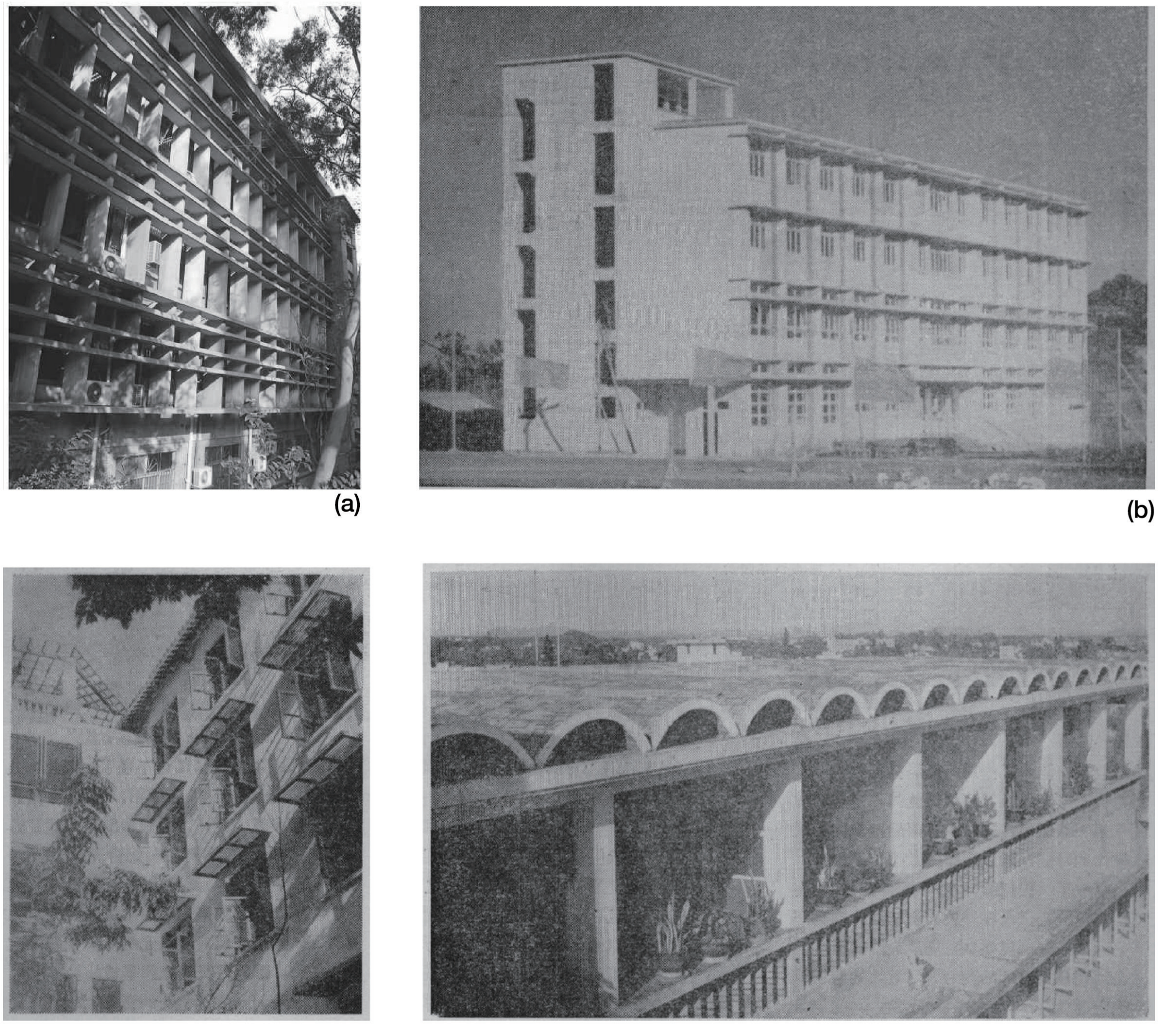
Though careful thought went into designing these shading systems, the quality of the materials presented major difficulties. Commonly utilized at the time, thin cement panels sipped under their own weight, causing cracks and corrosion of the steel reinforcing (Figure 2.9). Wooden louvers deteriorated and dropped off in direct sunlight and rain. Many of these shade systems were also fixed and non-adjustable, hence they were useless in the Lingnan area, where gloomy days are rather frequent. Because they couldn't readily modify the system to fit changing weather, this design control made people give natural lighting first priority over shading. During periods of economic hardship, the high cost of these shading systems made them impractical to implement. Moreover, there was a growing societal preference for simplicity in modern architecture with the flat roof (Tang Guohua, 2005). By 2002, due to safety concerns over the deteriorating condition of the façade shading system, South China University of Technology's campus management removed all window shading systems, retaining only the roof shading, which remained functional.

7 Xia Changshi (July 1903 – March 1996), born in Guangzhou, graduated with a degree in architecture from the Karlsruhe Institute of Technology in Germany and earned a doctorate from the Institute of Art History at the University of Tübingen. He was one of only two doctorate holders among China's first generation of architects, a renowned architect, architectural educator, and landscape architect, as well as a pioneer and founder of modern Lingnan architecture.

8 A hyperbolic arch roof helps avoid perpendicular solar rays due to its unique curved geometry. Unlike flat roofs, which are directly exposed to the sun's rays during midday, the sloping surfaces of a hyperbolic arch are angled to reduce exposure to direct sunlight from above. The curved shape deflects much of the sunlight, especially when the sun is at its highest, minimizing heat absorption.

Figure 2.8 Window and Roof Shading System of Xia Changshi

Source: Xia Changshi, 1958



(a) (b) (c) (d)

Figure 2.9 Material defects in window shading systems of Xia Changshi

Source: Tang Guohua, 2005.

In 2010, researchers from the Chinese State Key Laboratory of Subtropical Building Science (亚热带建筑科学国家重点实验室) used ECOTECT[9] to **simulate daylight and solar radiation for the window shading system on the south façade of the laboratory at Zhongshan Medical College**, designed by Xia Changshi. Their analysis of the wind environment also included PHOENICS[10].

The experimental results showed that the solar radiation simulations confirmed the shading system was highly effective at blocking direct sunlight, allowing only 4.7% direct sunlight to reach the windows and blocked 64.8% of diffuse sunlight. However, since the shading structure covers almost all of the south facade, it also did some impact on indoor natural daylight and ventilation. The average illuminance on work surfaces decreased by 21.6%. The wind simulations indicated that the shading devices also slightly reduced indoor airflow. (Qi Baihui, et al. 2010)

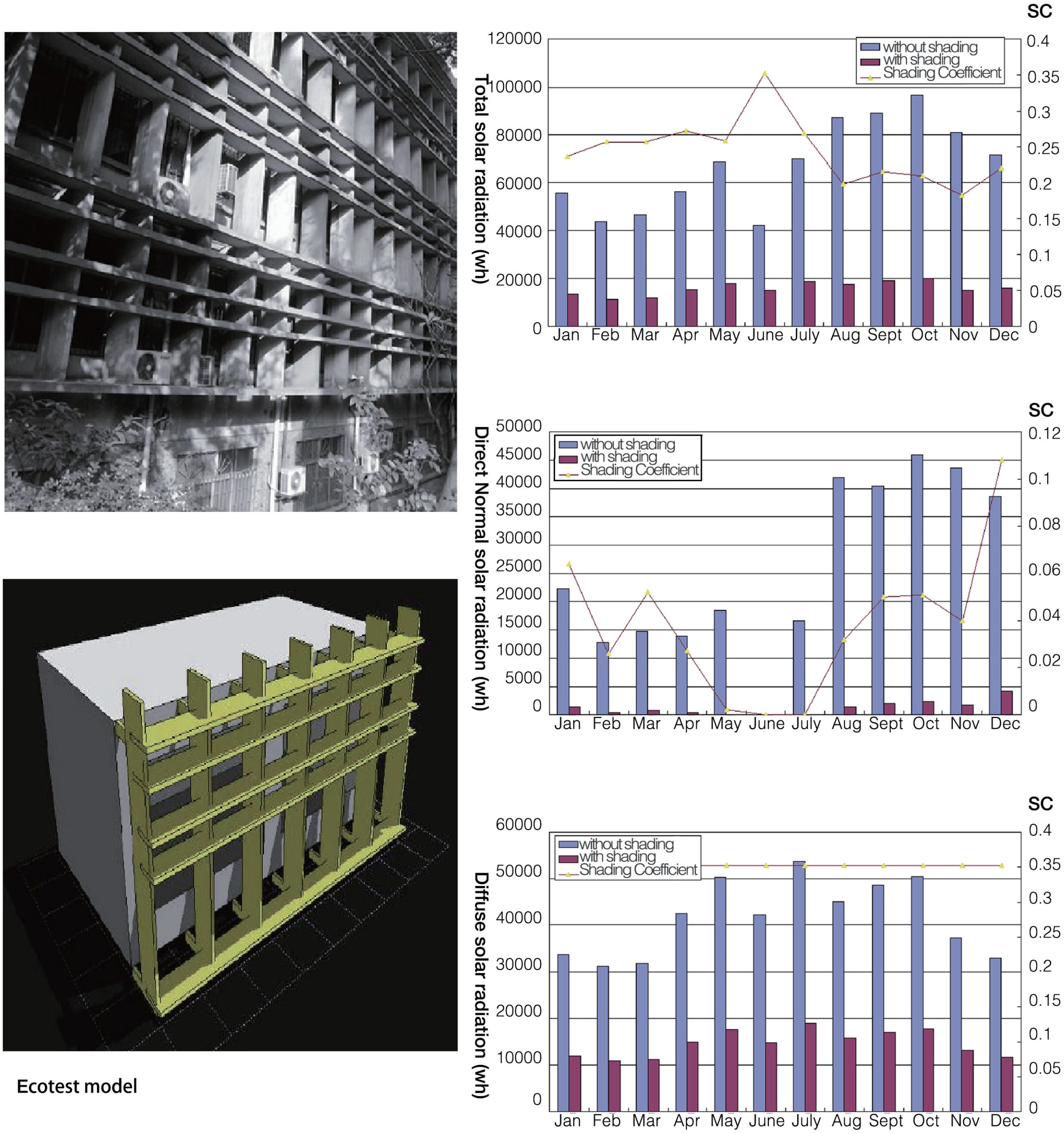
Figure 2.10 shows that, in the absence of a shading system, the total solar radiation on south-facing windows is lower in summer than in winter. While the experimental results confirm that the **shading system is highly effective throughout the year, shading is not necessary during all seasons. In winter, the priority is to allow more sunlight into interior spaces, which helps to reduce heating energy consumption.** Therefore, in this region, I believe that shading design should be considered secondary, with greater emphasis placed on meeting the requirements for ventilation and daylight. Summer diffuse solar radiation dominates over winter direct solar radiation. Fixed shading devices are ineffective and may block indoor illumination and airflow due to diffuse radiation from many directions. Natural ventilation helps cool and dehumidify indoor rooms in warm, humid conditions.

9 Autodesk Ecotect Analysis is a professional building performance analysis software, mainly used for building energy efficiency assessment and sustainable design.

10 PHOENICS (Parabolic Hyperbolic Or Elliptic Numerical Integration Code Series) is a computational fluid dynamics (CFD) software created by CHAM (Concentration, Heat and Momentum Limited).

Figure 2.10 Solar radiation simulation result for the window shading system on the south façade of the laboratory at Zhongshan Medical College

Source: Qi Baihui, et al. 2010.



Shading devices are a crucial part of architectural design, especially when energy economy and cooling load reduction are first concerns in building design. Although shading devices may not be the primary priority in the Lingnan region when HVAC systems are not present, their importance increases in structures that use air conditioning. In Solar Control and Shading Devices, Aladar and Victor Olgyay emphasize in the Economy chapter that well-designed shading systems can greatly reduce cooling demands. varying building orientations have varying thermal affects, thus careful design is needed. The equilibrium between these effects directly affects the expense of mechanical cooling and the investment in shading devices. **To optimize the efficacy and financial advantages of shading devices, the architectural design process must follow a structured approach:**

1.The arrangement of the whole building layout, determining the orientation of the elevations.
2.The size and distribution of the openings, which determine the heat transmission of the elevation.
3.The proper design of the shading devices, which will result in economy only if they work efficiently. (Victor Olgyay,et al. 1957)

Based on solar angles and orientations, the Olgyay brothers divided shade devices into three categories: horizontal, vertical, and eggcrate type, each with different uses. (Figure 2.1.0） **Horizontal shading devices are ideal for south-facing windows, effectively blocking high-angle sunlight in summer while allowing low-angle winter sunlight to penetrate, thus supporting passive heating**. Horizontal type devices are ideal for south-facing windows, effectively blocking high-angle sunlight in summer while allowing low-angle winter sunlight to penetrate, thus supporting passive heating.（Victor Olgyay,et al. 1957)

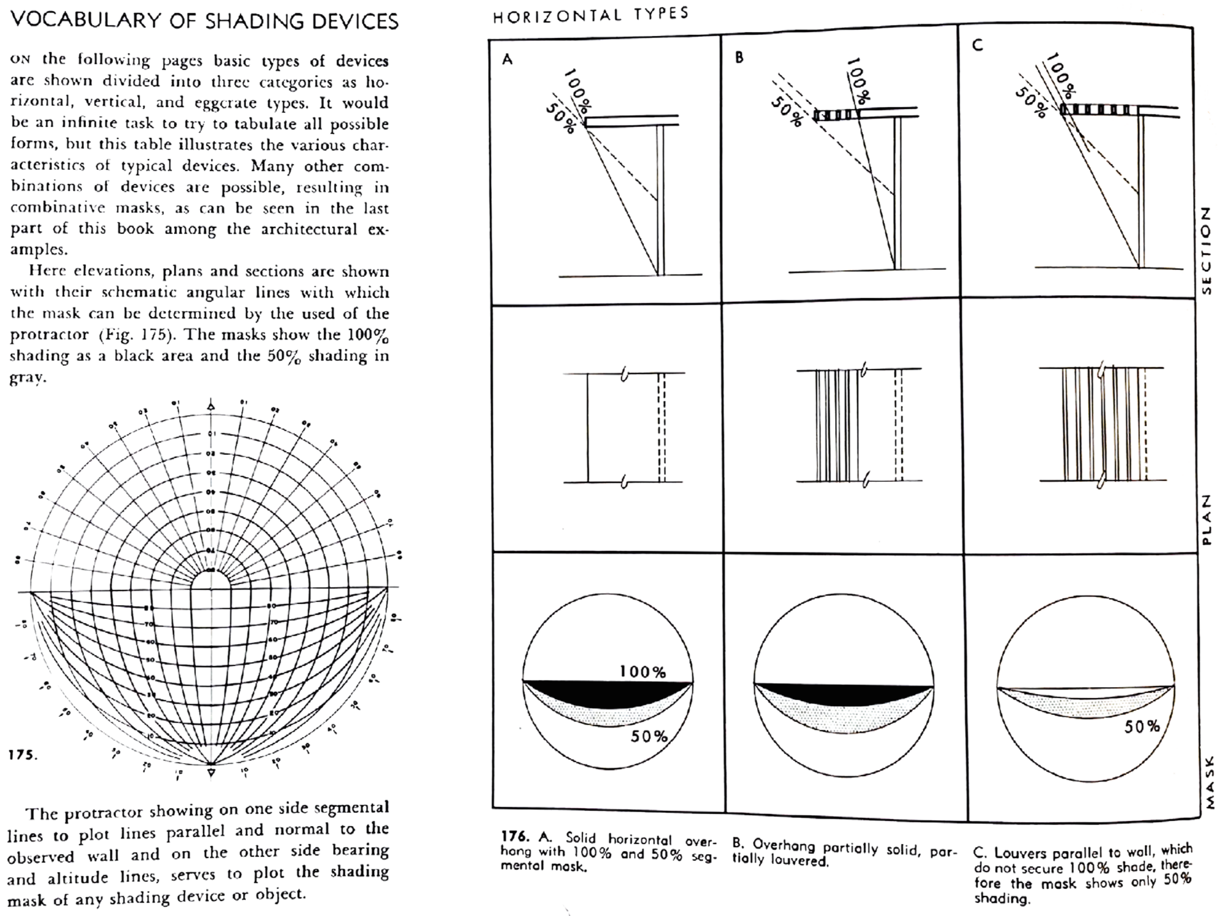
Vertical shading devices are more uesful for east- and west-facing windows, because the sun's rays are generally lower in the morning and late afternoon. By blocking this low-angle sunlight, vertical shading devices serve to lower glare and unwelcome heat absorption at these times. Vertical shading systems can reduce cooling loads while retaining natural light by managing sun radiation at important times. （Victor Olgyay,et al. 1957)

Eggcrate shading devices combine the properties of horizontal and vertical systems to generate a grid-like structure that allows for solar control from numerous directions. These devices are especially effective for windows that receive solar light from the southeast or southwest.Eggcrate systems' three-dimensional design enables for more precise control of solar gain, ensuring that heat is suppressed while maintaining visual openness and daylight penetration.((Aladar Olgyay, et al.1957)

The design of energy-efficient buildings depends much on shading devices, especially in areas needing air conditioning. Correct design and placement of these devices can greatly lower cooling needs while raising general building efficiency. By understanding the many types of shading devices—horizontal, vertical, and eggcrate—and incorporating them into the architectural design process.With the development of computer technology, there are many softwares on the market that can calculate shading masks, such as Ladybug, a plug-in based on Grasshopper, which can help architects better understand whether the design of the shading system is effective, optimize sun control, reduce energy consumption, and increase building sustainability.

Figure 2.1.0 The Vocabulary of Shading Devices

Source: Aladar Olgyay and Victor Olgyay, 1957. Solar Control and Shading Devices, Page 88-92



VOCABULARY OF SHADING DEVICES

ON the following pages basic types of devices are shown divided into three categories as horizontal, vertical, and eggcrate types. It would be an infinite task to try to tabulate all possible forms, but this table illustrates the various characteristics of typical devices. Many other combinations of devices are possible, resulting in combinative masks, as can be seen in the last part of this book among the architectural examples.

Here elevations, plans and sections are shown with their schematic angular lines with which the mask can be determined by the used of the protractor (Fig. 175). The masks show the 100% shading as a black area and the 50% shading in gray.

175.

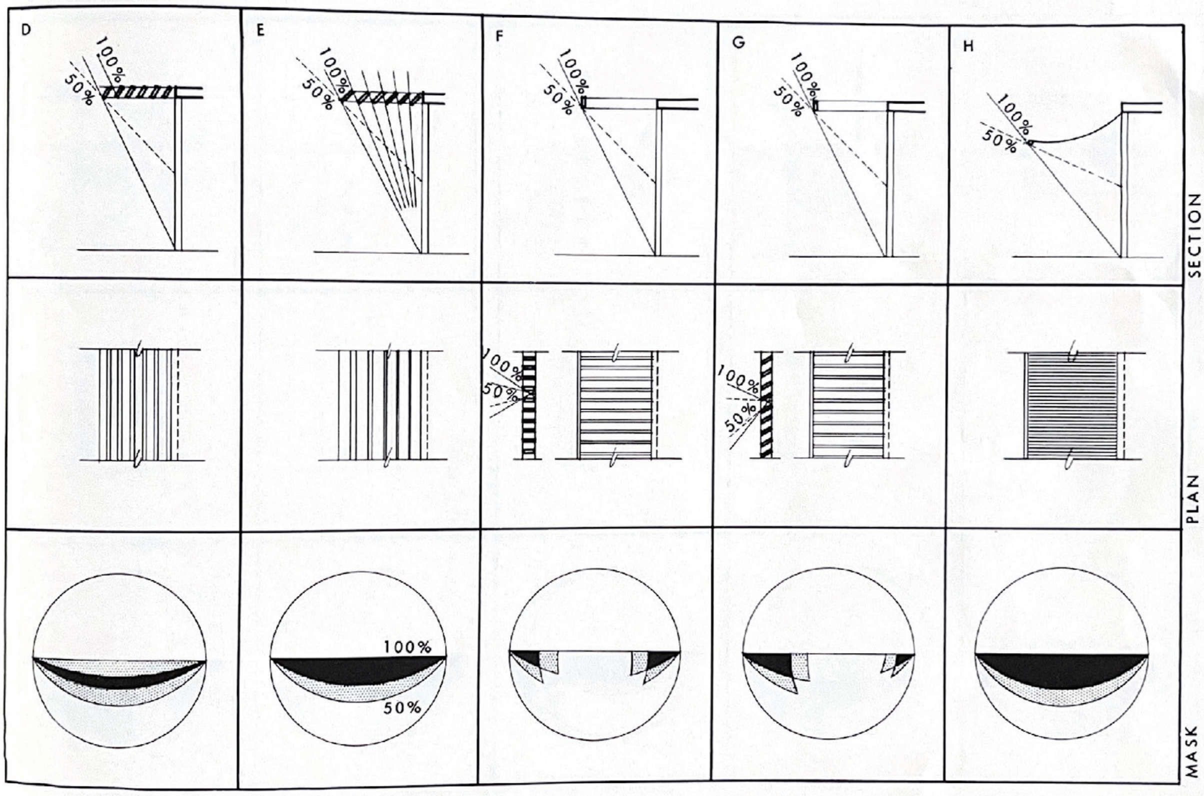
The protractor showing on one side segmental lines to plot lines parallel and normal to the observed wall and on the other side bearing and altitude lines, serves to plot the shading mask of any shading device or object.

176. A. Solid horizontal overhang with 100% and 50% segmental mask.

B. Overhang partially solid, partially louvered.

C. Louvers parallel to wall, which do not secure 100% shade, therefore the mask shows only 50% shading.

HORIZONTAL TYPES



177. D. Tilted louvers parallel to wall let in some sunrays at high altitudes, as shown in mask.

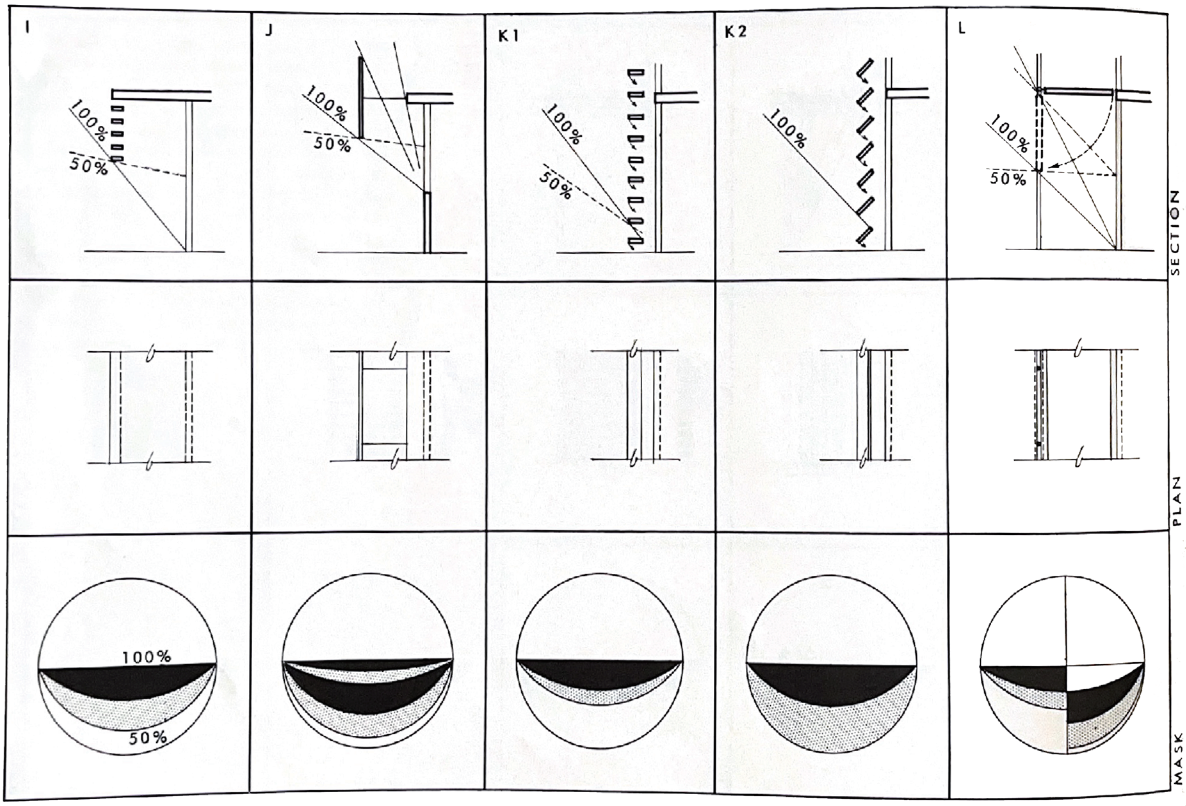
E. Tilted louvers parallel to wall, but unequally spaced will secure 100% shading at high sun altitudes also.

F. Overhangs with louvers perpendicular to wall will cut out sunrays from the sides.

G. Tilted louvers perpendicular to wall will have the same characteristics as type F, but the mask will be asymmetrical.

H. Canvas canopy will have same characteristics as a solid overhang.

HORIZONTAL TYPES



178. I. Horizontal louvers hanging from solid overhang might result in a large segmental mask.

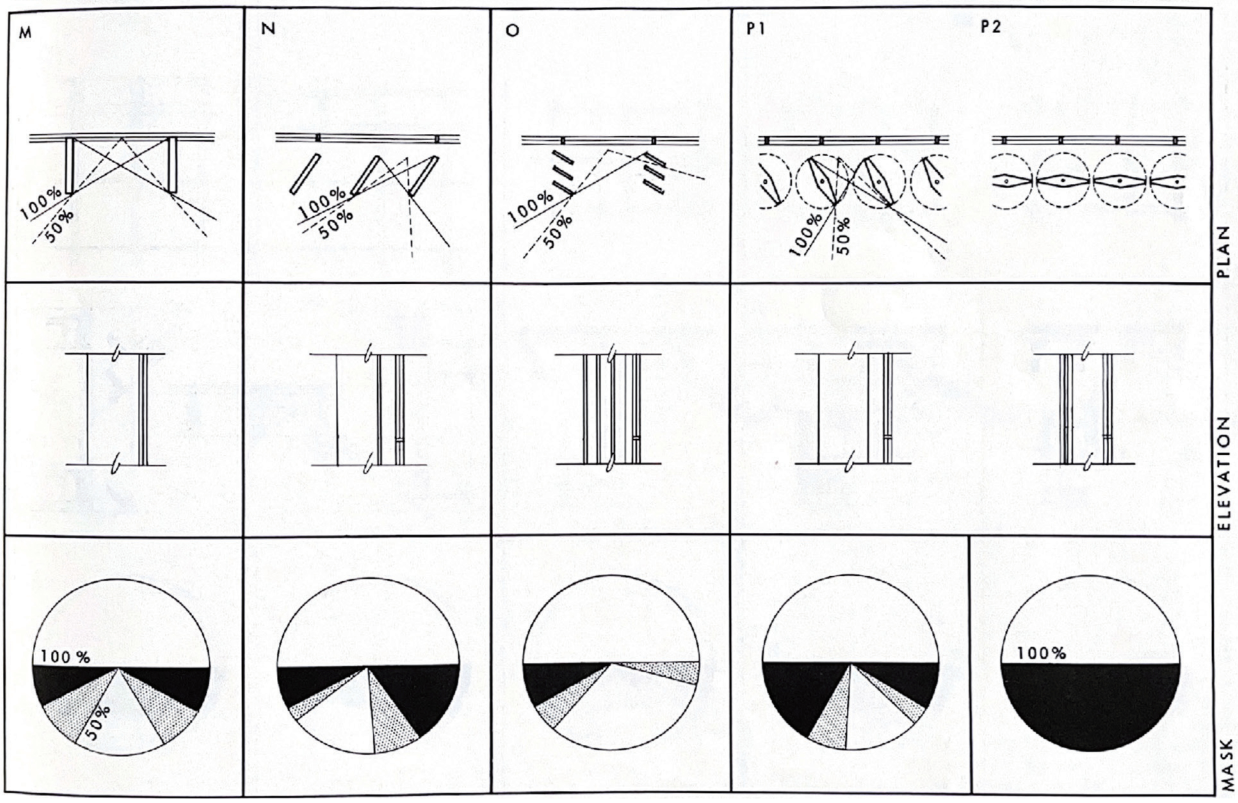
J. A solid strip parallel to wall cuts out the lower rays of the sun. If the strip is made of heat-repellent glass, it will not secure 100% shading.

K1. Movable horizontal louvers change their mask characteristics according to their positioning.

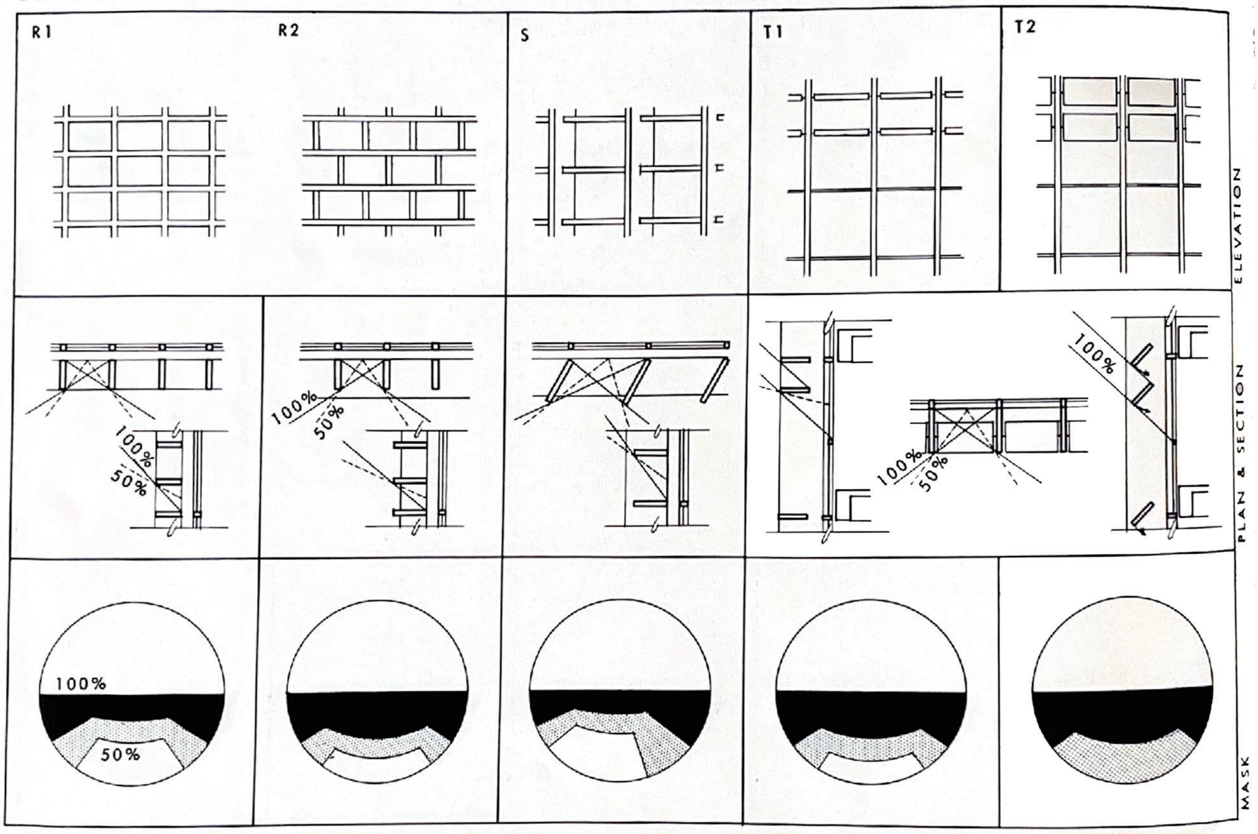
K2. The same device as shown before in horizontal positioning is tilted in 45° angle.

L. Movable horizontal device (as in example on pages 122-123) will have different mask characteristics.

VERTICAL TYPES



EGGCRATE TYPES



180. Eggcrate types are combinations of horizontal and vertical types and therefore their mask is a superimposed diagram of the two masks. As type "A," a solid horizontal overhang combined with type "M," a solid vertical type gives type "R." R_1 and R_2 could have the same mask, depending on their horizontal and vertical measurements.

S. Solid eggcrate with slanting vertical fins results in an asymmetrical mask.

T1. Eggcrate device with movable horizontal elements change their mask characteristics according to their positioning.

T2. The same device, shown before in horizontal position, is tilted in 45° angle.

2.1.3 Natural ventilation design

Passive ventilation refers to the method of introducing and expelling air in an indoor environment without the utilization of mechanical equipment. It pertains to the movement of exterior air into an indoor environment due to pressure differentials created by natural factors.(Wikipedia contributors, 2025) In the warm and humid Lingnan region, natural airflow helps get rid of excess moisture indoors and spreads heat from building surfaces. This greatly improves the indoor environment and makes it more comfortable for people inside.

Buildings experience two types of natural ventilation: wind-driven ventilation (Figure 2.11) and stack ventilation (Figure 2.12). **Wind-driven ventilation** results from the pressure differentials generated by wind around a building or structure, with apertures on the perimeter facilitating airflow through the interior. **Buoyancy-driven ventilation (stack ventilation)** arises from the directed buoyancy force generated by temperature differentials between the interior and outside environments.(Linden, P. F. 1999) Consequently, stack ventilation can occur with reasonably consistent airflow on hot summer days, even in the absence of wind.

The formula for natural ventilation typically quantifies airflow through openings based on pressure differences caused by wind or thermal effects. A commonly used equation is: (Etheridge, D,et al.1996)

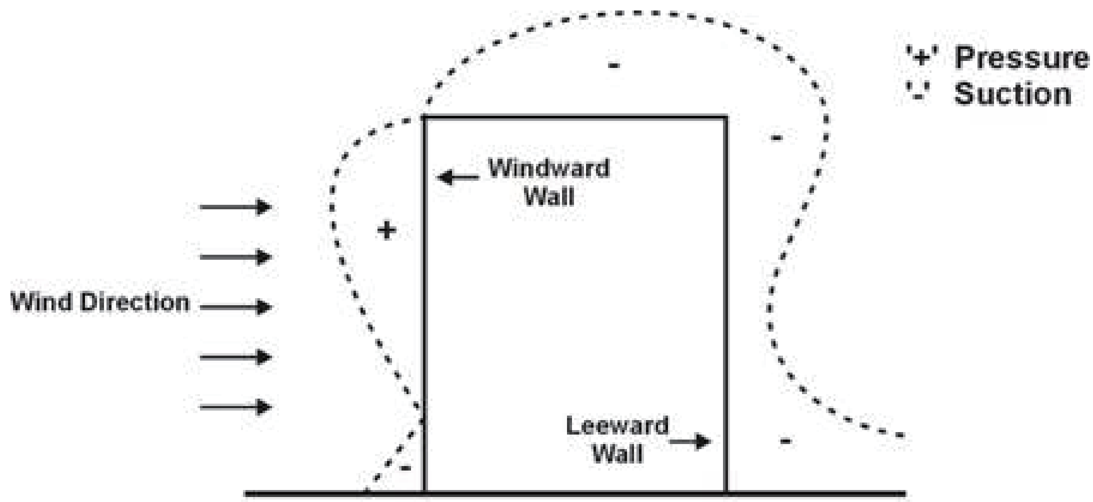
$$Q = C_d \cdot A \cdot \sqrt{\frac{2 \cdot \Delta P}{\rho}}$$

Where:

- Q: Airflow rate (m³/s)
- C_d: Discharge coefficient (dimensionless, typically between 0.6 and 0.7 for windows and vents)
- A: Area of the opening (m²)
- ΔP: Pressure difference across the opening (Pa)
- ρ: Air density (kg/m³, approximately 1.2 kg/m³ at standard conditions)

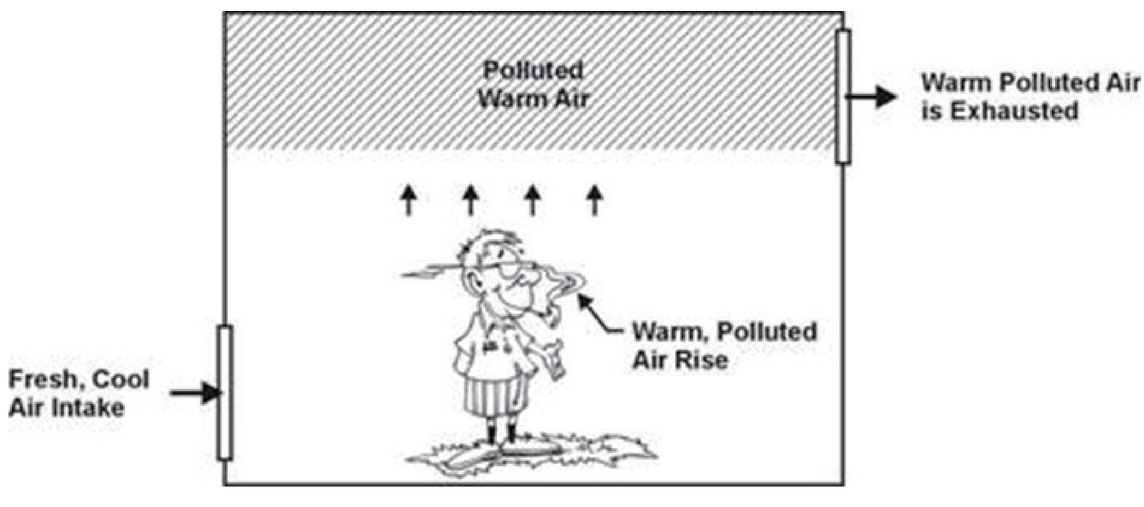
Buoyancy-driven ventilation design (stack ventilation), however, has to be especially sensitive to the quality of air intake in metropolitan settings. Because of street-level pollutants and heat from urban surfaces, lower air intakes on buildings often draw in warmer, more contaminated air. Natural ventilation's efficacy may be compromised by this since the entering air can be less efficient for cooling and might bring contaminants into the inside environment.

Figure 2.11 The Mechanism of Wind driven ventilation
Source: gbtech.emsd.gov.hk, 2020



https://greenhome.osu.edu/natural-ventilation

Figure 2.12 The Mechanism of Stack ventilation
Source: gbtech.emsd.gov.hk, 2020

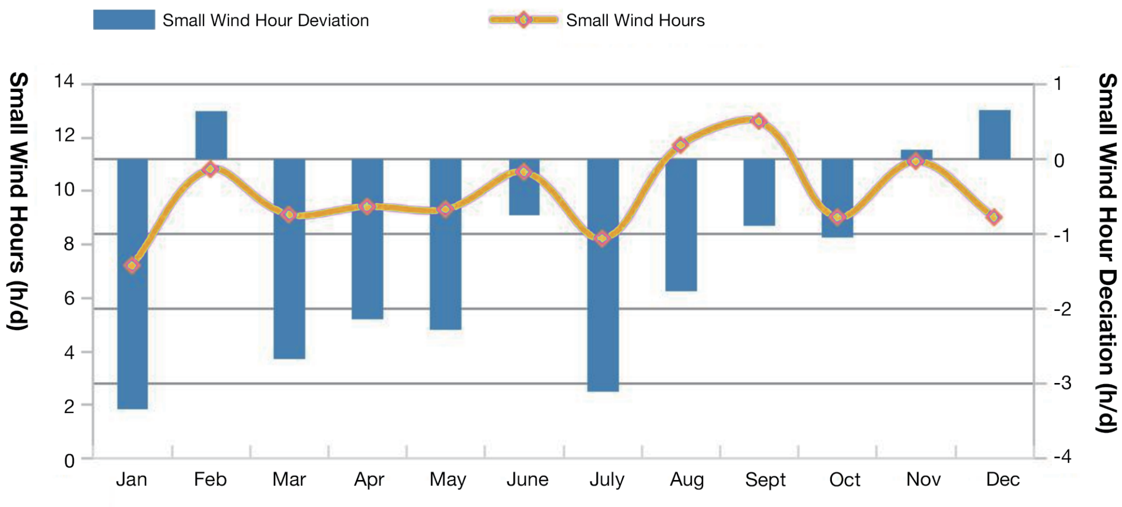


https://greenhome.osu.edu/natural-ventilation

From the perspective of wind speed and calm wind characteristics throughout the year, the proportion of calm wind in each season is relatively high, 18.4% in spring, 14.8% in summer, 17.9% in autumn, and 18.0% in winter, indicating that Guangzhou is in an environment with relatively low wind speed as a whole. At the same time, the wind speed in summer is significantly higher than in other seasons, which may be related to the strengthening of typhoon activities and summer monsoon. From the distribution of light wind hours in Figure 2.13, it can be seen that the number of light wind hours in Guangzhou shows seasonal fluctuations, with more light wind hours in summer and relatively fewer in spring and autumn.

The wind direction characteristics of Guangzhou have obvious seasonal changes. The wind direction distribution in spring is more scattered,the wind direction is mainly northerly and southeasterly. In summer, the wind direction is concentrated in the southeasterly direction. The wind direction distribution in autumn is still mainly northerly and northeasterly, while in winter it is mainly northerly and northeasterly.(Figure 2.14)

Figure 2.13 Monthly Small Wind Hours and Variance in Guangzhou for 2023
Source: Guangzhou Weather. 2023
Unit: Hours/Day

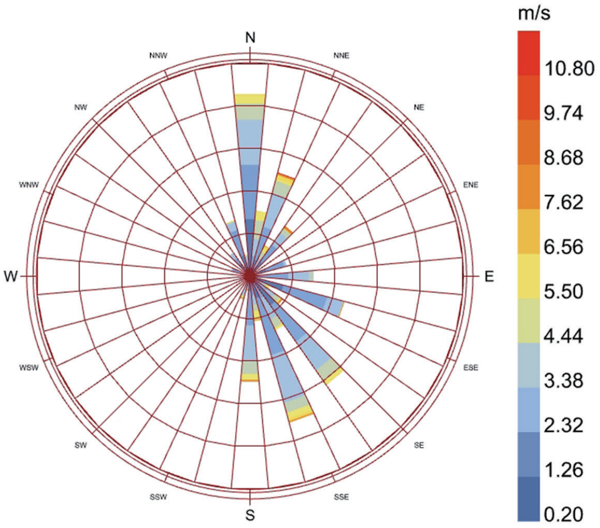


http://www.tqyb.com.cn/gz/climaticprediction/bulletin/

Figure 2.14 The Wind roses of Guangzhou in different seasons

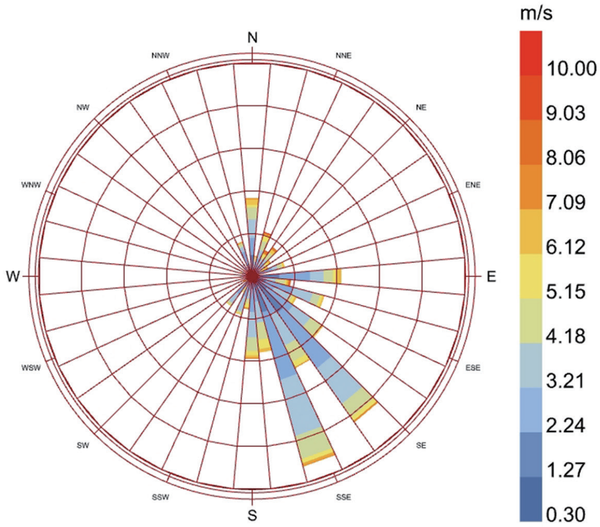
Source: Created by the author, 2024

Spring



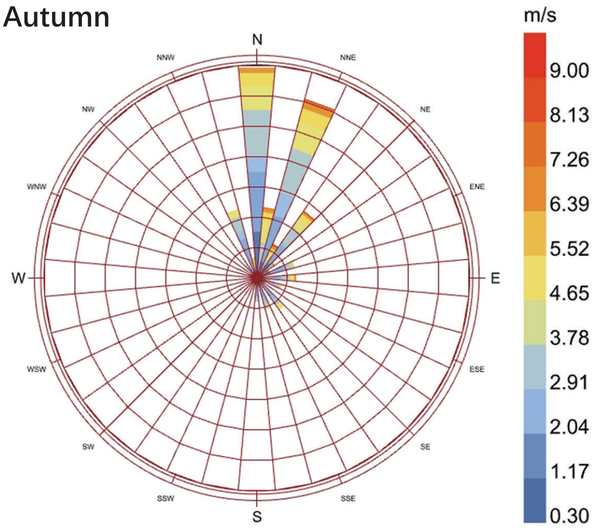
Wind Speed (m/s)
city: GUANGZHOU
country: CHN
time-zone: 8.0
source: IWEC Data
period: 3/1 to 5/31 between 1 and 23 @1
Calm for 18.38% of the time = 389 hours.
Each closed polyline shows frequency of 2.9% = 50 hours.

Summer



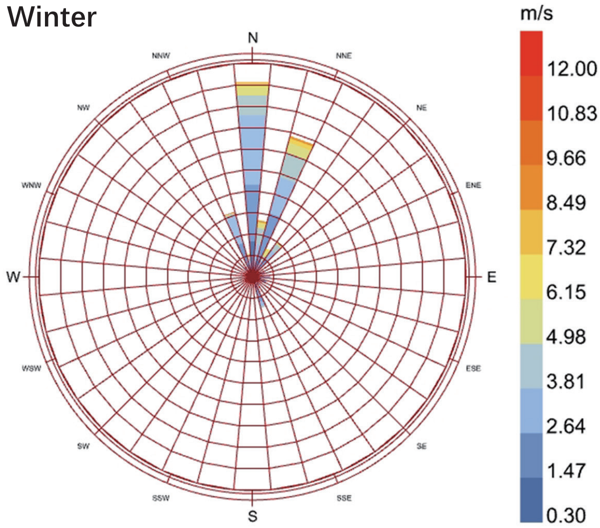
Wind Speed (m/s)
city: GUANGZHOU
country: CHN
time-zone: 8.0
source: IWEC Data
period: 6/1 to 8/31 between 1 and 23 @1
Calm for 14.84% of the time = 314 hours.
Each closed polyline shows frequency of 2.8% = 50 hours.

Autumn



Wind Speed (m/s)
city: GUANGZHOU
country: CHN
time-zone: 8.0
source: IWEC Data
period: 9/1 to 11/30 between 1 and 23 @1
Calm for 17.92% of the time = 375 hours.
Each closed polyline shows frequency of 2.9% = 50 hours.

Winter



Wind Speed (m/s)
city: GUANGZHOU
country: CHN
time-zone: 8.0
source: IWEC Data
period: 12/1 to 2/28 between 1 and 23 @1
Calm for 17.97% of the time = 372 hours.
Each closed polyline shows frequency of 2.9% = 50 hours.

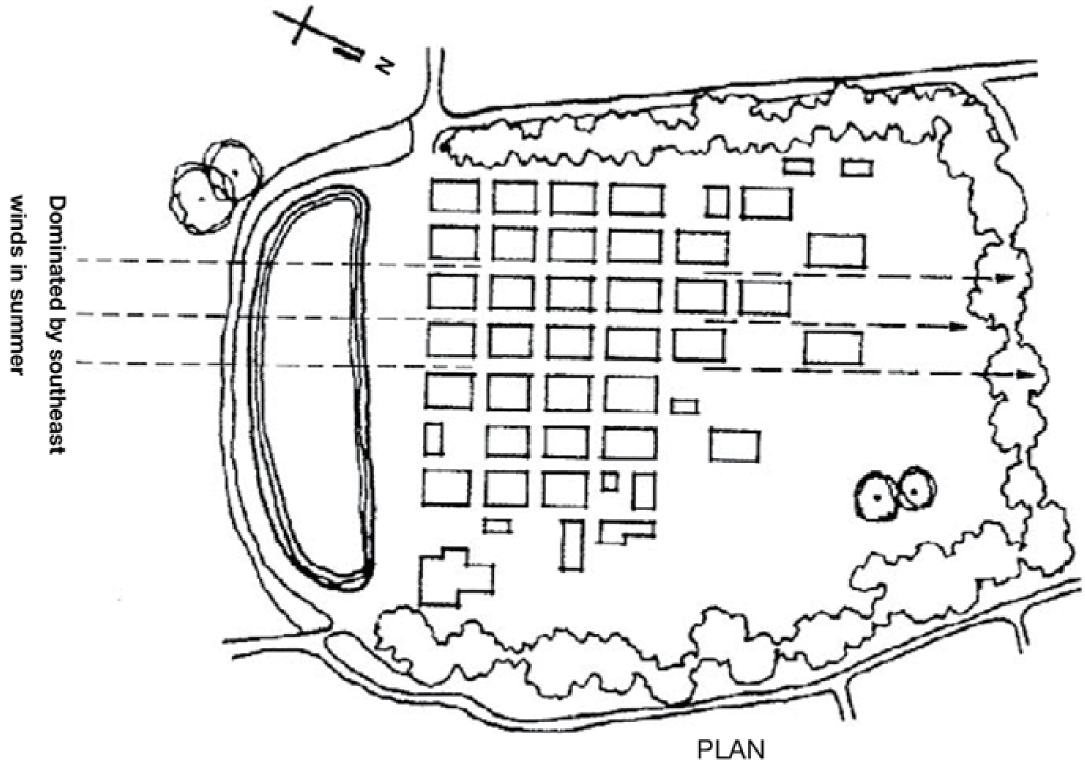
Traditional Lingnan dwellings were cleverly built in the past to maximize natural ventilation and apply other climate-adaptive building strategies, therefore creating comfortable indoor settings without contemporary electrical equipment. These techniques let residents of the area deal with the hot and muggy summer. **The layout of the villages facilitated the natural flow of air, allowing wind to enter and pass through the village;** This ventilation helps to remove excess heat and moisture, greatly improving thermal comfort indoors.

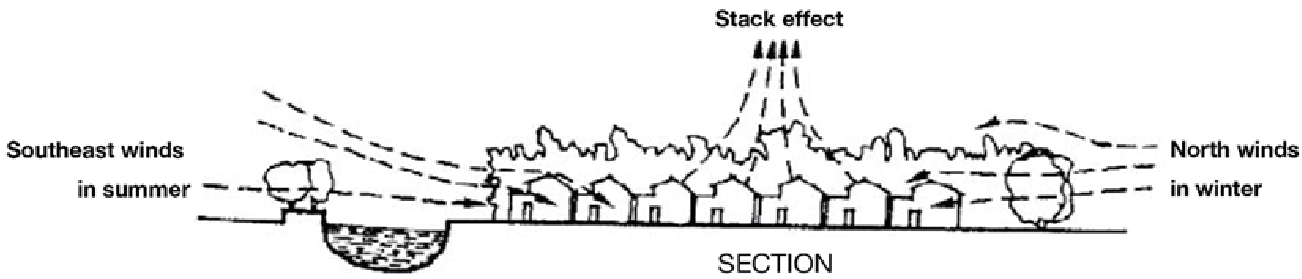
For example, in Guangzhou, traditional village layouts often followed a grid or comb-like structure. In comb-like layouts villages (Figure 2.15), residential buildings were typically a courtyard house with rooms on three sides or four sides (Figure 2.2), Public buildings such as ancestral halls, family temples, and private schools are often located in the center of the village. In front of these clusters, there was often a small open-air plaza used for drying grain. The plaza was usually followed by a pond, which could be crescent-shaped, semicircular, or irregular in form. These ponds served multiple purposes, such as fish farming, irrigation, and flood control. However, if the village was near a river, a separate pond was often unnecessary. Behind the cluster of the buildings, hills or forests provided additional shelter. (Zeng Zhihui,2010)

The arrangement of building units within these clusters was very structured and aligned. **Narrow passageways known as "cool alleys" ran between the rows of houses in a southeast direction, providing traffic pathways and ventilated pathways.** Houses often had side openings facing these alleys, allowing cool air to flow into the living spaces.

The direction of comb-like layout communities was carefully selected to match area wind patterns (Figure 2.14). Villages were built facing east to south to take advantage of the southeast monsoon, which dominates during the summer. This allowed the summer winds to flow parallel to the "cool alleys," allowing breezes to travel deep within the cluster without losing power. In the winter, the hills or forests behind the settlement provide as a natural shield from harsh northern winds, providing relief from the winter chill.

Figure 2.15 The Typical Comb-like Village Layout
Source: Wang Jing et al, 2013

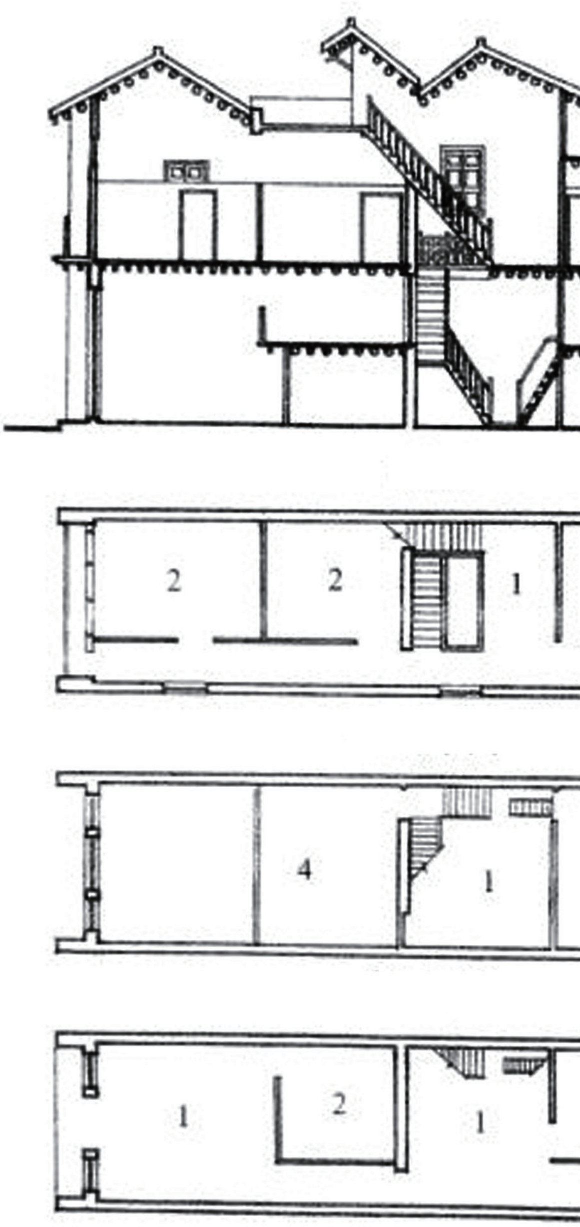




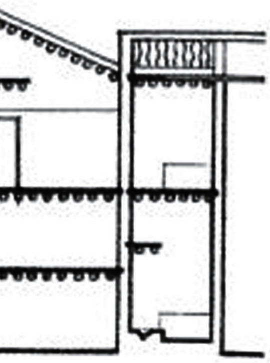
In terms of building typology, **the Courtyard house** (Figure 2.2) and **the bamboo house** (Figure 2.1.2 and Figure 2.1.3) are the most representative residential forms in the Lingnan region. The layout of the courtyard house is centered around a central courtyard, with a ventilation system facilitated by doors and windows on both sides of the cold alley outside the house. Similarly, the bamboo house is also centered on a patio, which is narrower and deeper than the patio of the courtyard layout. Typically, the patio in the bamboo house is located at the back, creating a connected ventilation system with the cold alley and the front hall.

Both architectural typologies utilize a clever spatial layout not only to guide and direct airflow into the building's interior during the summer, but also to rely solely on stack ventilation under windless conditions, which helps remove excess heat and moisture, thereby enhancing the indoor thermal environment. This stack ventilation design is particularly crucial in Lingnan, where windless conditions with wind speeds of ≤ 1.5 m/s occur up to 30% of the time (Figure 2.13).

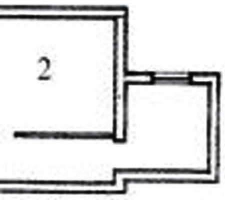
Figure 2.1.2 Bamboo House Typology: Resic
Source: Tang Guohua, 2005; “Lingnan's Hot a
Page 137



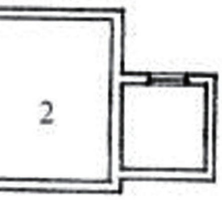
dential Building at No. 18 Jiefang North Road, Guangzhou
and Humid Climate and Traditional Architecture",



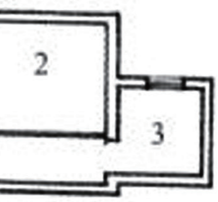
Section



The First floor plan

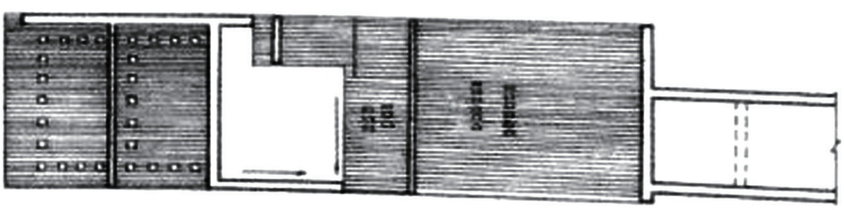


Mezzanine level plan



Grond floor plan

Facade

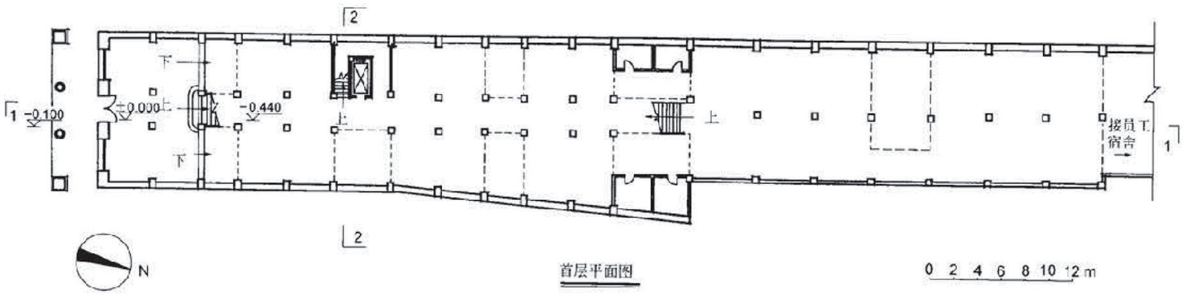


Roof Plan

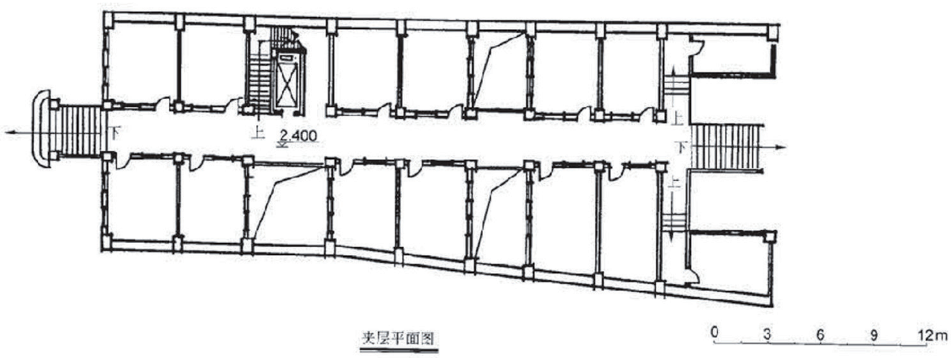
1 — Hall 2 — Room 3 — kitchen 4 — Prayer Room

Figure 2.1.3 Bamboo House with Multiple Patios Typology: Oriental Hotel

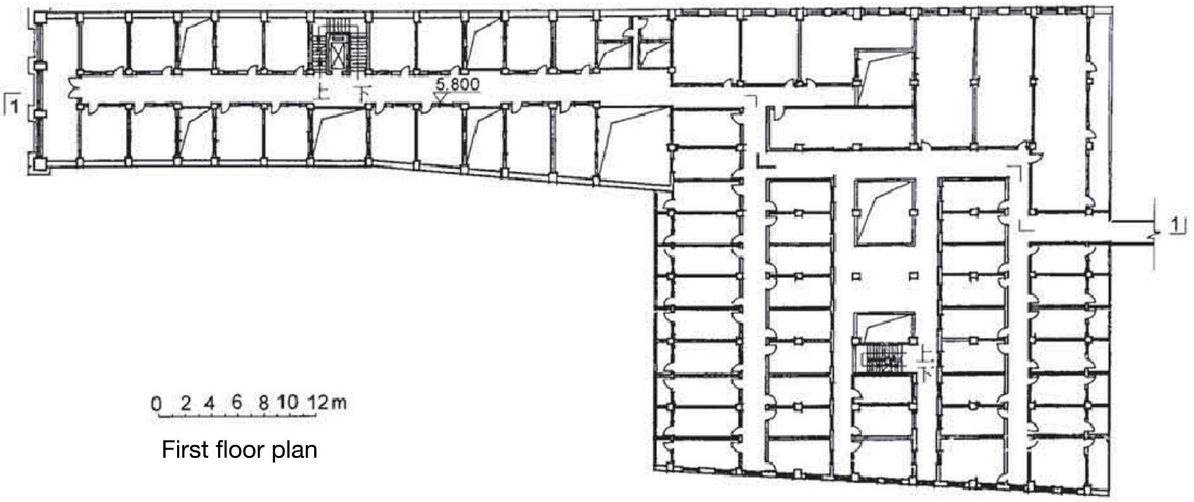
Source: Tang Guohua, 2000; “Selected Measure Drawings of Guangzhou Historical buildings”, Page 232



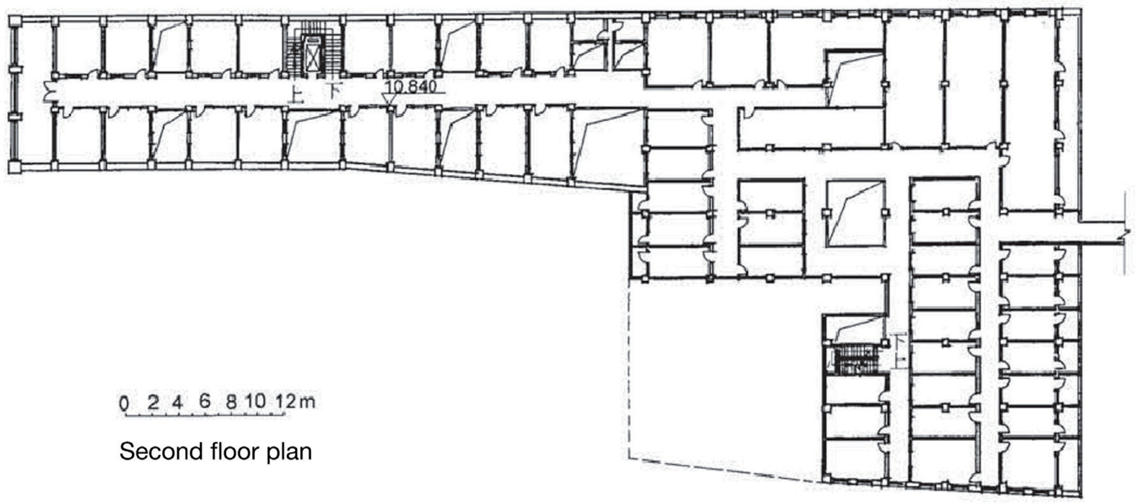
Ground floor plan



Mezzanine plan

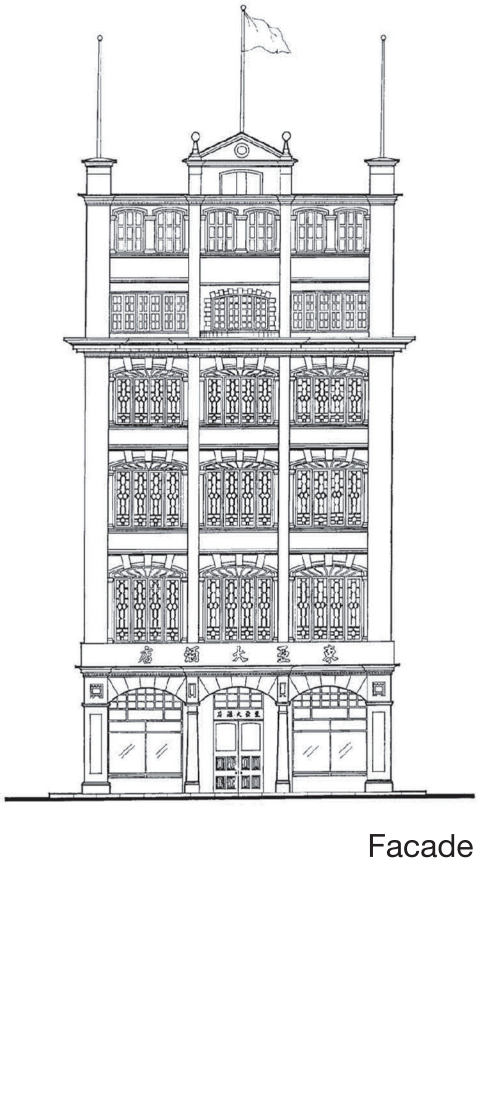


First floor plan



Second floor plan

Section 1-1



Facade

Zeng Zhihui and his team measured ventilation and thermal environments in summer 2008, when the average outdoor temperature was 30.2° C, to better understand typical residential building ventilation. For analysis, they chose two common dwelling building types. Courtyard house No. 16 in Daqi Village, Sanshui (Figure 2.16), Bamboo house No. 20 Baoyuan Road, Guangzhou (Figure 2.17). In addition to wind direction and speed, the team measured air temperature, relative humidity, and the WBGT index within the houses.

On the measurement day, two types of courtyard houses and Bamboo House) adopted two methods of ventilation: thermal pressure ventilation and wind pressure ventilation. Courtyard houses mainly relied on stack ventilation. Although it faced the main wind direction in summer, the wind-driven ventilation effect was poor, the airflow was unstable, and it was difficult to effectively utilize the wind from the cool alley. In contrast, the spatial layout of the bamboo house was more conducive to ventilation. Its design guided the street wind into the inner hall through the street-facing windows, and then flowed to the cool corridor. The air pressure drop accelerated the airflow and enhanced the ventilation of the bedroom. The air was finally discharged through the patio. The thermal pressure difference caused the air to circulate continuously, and the ventilation effect was good even in light wind conditions. (Figure 2.1.1)

In both typologies, the indoor temperatures in the patio are the highest, reaching about 32 degrees Celsius. The average temperature in other indoor spaces of the bamboo house is about 28 degrees Celsius. The average temperature of the indoor space of the courtyard house is slightly lower than that of the bamboo house, reaching around 27 degrees Celsius. In terms of humidity comparison, the indoor humidity of the two types is not much different, both around 75%.

The courtyard house has a peak WBGT of about 29 ° C in its patio, while the bamboo house has 26 ° C. The various patio designs influence ventilation and heat dissipation. Narrower and higher bamboo house patios increase vertical temperature differential. This improves stack effect, improving natural ventilation and heat removal. The courtyard house's patio, which is broader and more open, accumulates more heat due to its inefficiency in stimulating upward air flow, raising its WBGT index.

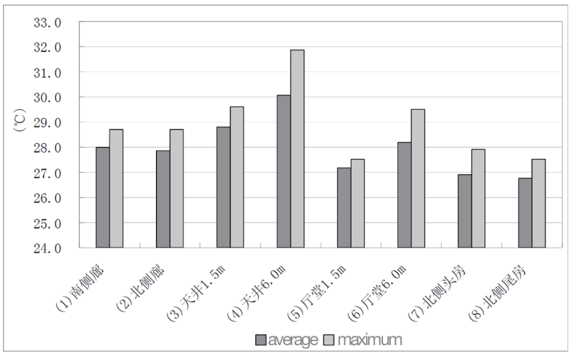
PMV and PPD demonstrate that both housing typologies are more comfortable in the morning for thermal comfort. But bamboo buildings could provide higher internal thermal comfort even at noon. The afternoon PMV of 0.52 (sitting) in the courtyard house living room generates a PPD of 11%. This number is slightly above 10% but meets ISO 7730 comfort standards. In contrast, PPD values are below 10% in all bamboo house spaces, including the living room. The bamboo house keeps PPD values below 10% throughout, even the living room.

Due to its better airflow design, the bamboo house exceeds the courtyard house in ventilation and thermal comfort. **Lingnan architecture commonly combines stack ventilation and wind-driven ventilation. When aligned, these two systems can boost each other, although stack ventilation can impair wind-driven ventilation** (Zeng Zhihui, 2008).

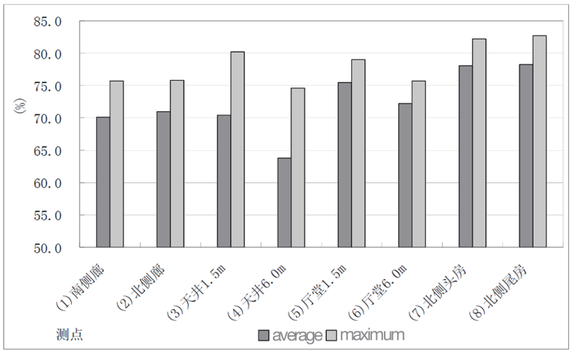
Figure 2.16 Measurement result of Courtyard House No. 16 in Daqi Village, Sanshui

Source: Zeng Zhihui, 2008

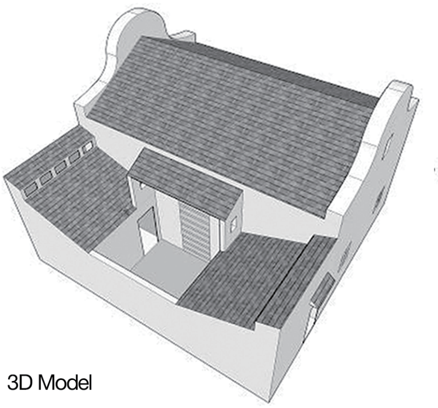
The location of residential building in the village



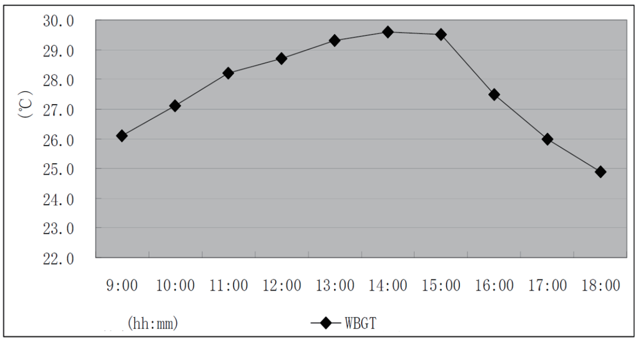
Indoor temperature statistics



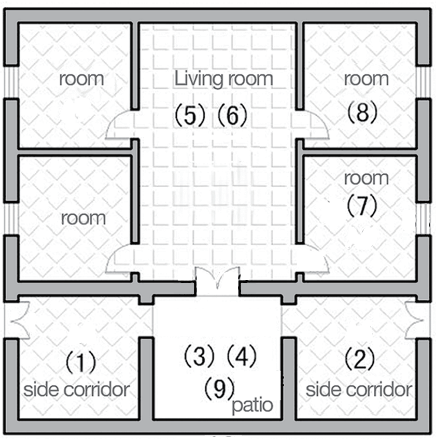
Indoor humidity statistics



3D Model



The WGBT index of the patio



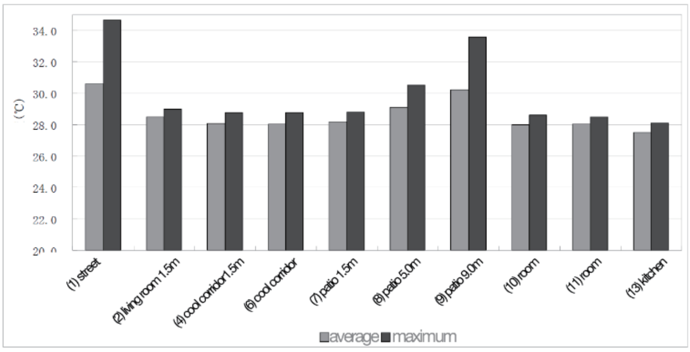
Plan and Measuring position

	Living room		
	In the morning	In the afternoon	
PMV	0.19	0.52	Sitting
PPD	6%	11%	
PMV	0.58	0.86	Standing
PPD	12%	21%	
	Room		
	In the morning	In the afternoon	
PMV	0.14	0.38	Sitting
PPD	5%	8%	
PMV	0.55	0.74	Standing
PPD	11%	16%	

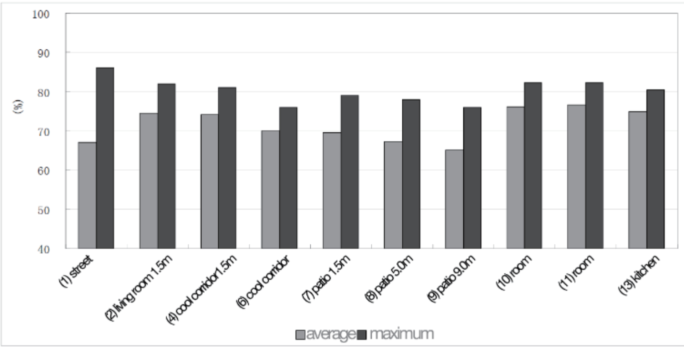
Note: PMV is the predicted mean voting value, PPD is the predicted percentage of dissatisfaction

PMV-PPD index

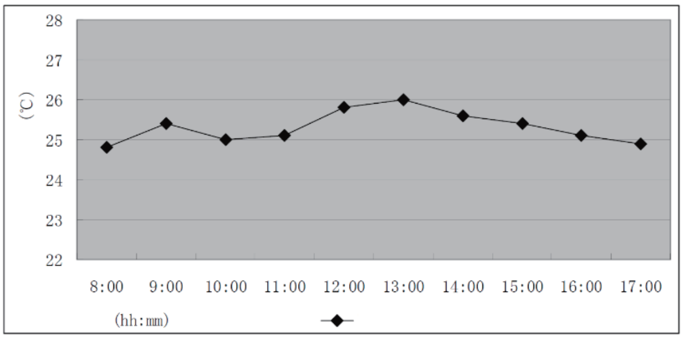
Figure 2.17 Measurement result of Bamboo House No. 20 Baoyuan Road, Guangzhou
Source: Zeng Zhihui, 2008



Indoor temperature statistics



Indoor humidity statistics

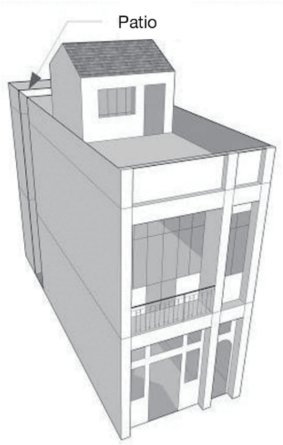


The WGBT index of the patio

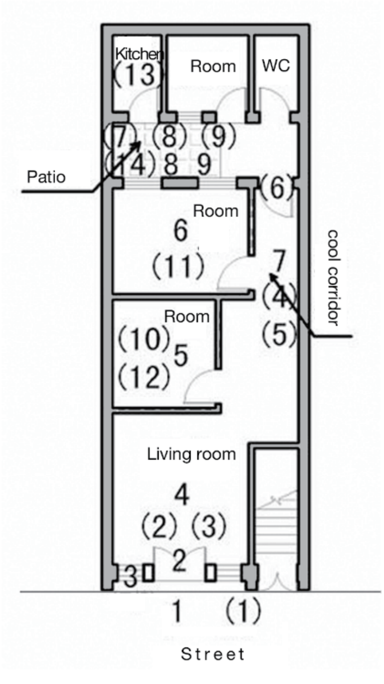
	Living room		
	In the morning	In the afternoon	
PMV	0.32	0.25	Sitting
PPD	7%	6%	
PMV	0.73	0.67	Standing
PPD	16%	14%	
	Room		
	In the morning	In the afternoon	
PMV	0.23	0.17	Sitting
PPD	6%	6%	
PMV	0.65	0.6	Standing
PPD	14%	12%	

Note: PMV is the predicted mean voting value, PPD is the predicted percentage of dissatisfaction

PMV-PPD index



3D Model



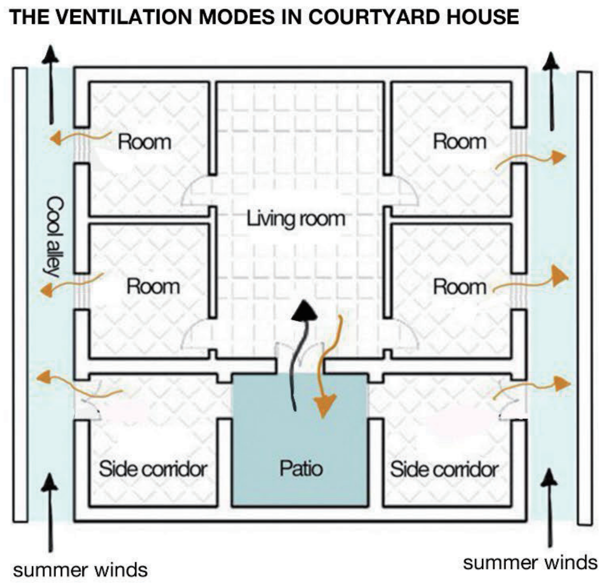
Plan and Measuring Positions

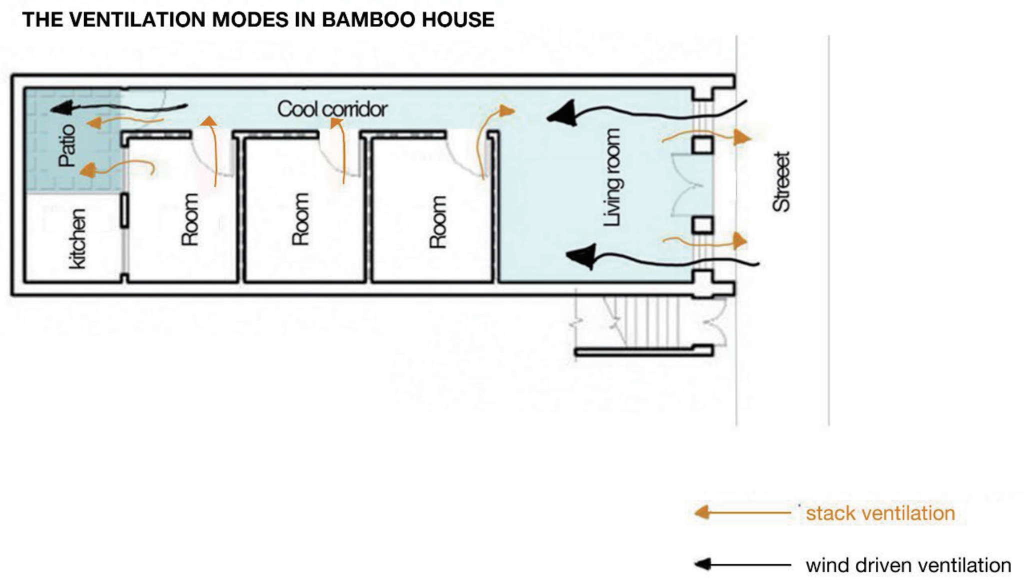
Facade

Patio

On-site photos

Figure 2.1.1 The stack and wind driven ventilation in two typical residential houses in Lingnan
Source: Created by author, 2024





Three main components make a well-designed ventilation system: air inlet, air output, and circulation path. In the bamboo house, the doors and windows on the front wall serve as single- sided air inlets and outlets, while the cool corridor functions as an airflow path. A patio adds still another consistent air entrance and output, allowing cross ventilation. The narrow and height measurements of the patio produce a higher vertical temperature differential, thereby improving the stack effect and increasing the suction of warm air upward. Cool air simultaneously comes from the cool corridor towards the patio, matching the wind-driven ventilation, therefore enhancing the whole ventilation system（Zeng Zhihui, 2010）.

Apart from the patio design, the windows and doors of the bamboo house greatly help to enhance airflow. While preserving privacy, Distinctive doors[11] (Figure 2.21) and high-light windows (Figure 2.22) optimize airflow on the street-facing façade. For example, doors and windows account for about 46% of the wall area in the house on No. 20 Baoyuan Road (Figure 2.17), therefore enabling plenty of air movement. Furthermore, **instead of masonry walls, interior areas are split by partial-height or openwork partitions** (Figure 2.23), therefore allowing continuous airflow in the top parts of rooms. Without interference between rooms, this design encourages improved air circulation all around the house.

11 A standard Tanglong door(趟栊门) is made up of three doors. The first is a foot door, which blocks the view of passers-by outside. The second door is called a sliding door, which looks like a large wooden frame with more than a dozen logs across the middle. The third door is the real main door.

Figure 2.21 The Distinctive doors design in bamboo house
Source: Zeng Zhihui, 2010

Figure 2.22 Different types of high-light windows in bamboo house
Source: Zeng Zhihui, 2010

Figure 2.23 Partial-height or Openwork Partitions in bamboo house
Source: Zeng Zhihui, 2010

2.1.4 Natural ventilation difficulties in morden high-rise buildings

I**n modern high-rise residential design, many buildings adopt a tower form to spare land on buildable sites and create compact floor plans.** However, this design often limits each unit's ability to achieve optimal orientation, **making it difficult to capture southeast summer winds for natural ventilation.** Additionally, the interior layout frequently places rooms on both sides of the unit, which further restricts airflow. At night, when bedroom doors are closed for sleeping, each room becomes single-ventilated, further reducing ventilation effectiveness. (Figure 2.24)

In some high-rise residential layouts, stairwells, with their narrow and tall structures, can function much like the patios in traditional bamboo houses, acting as vertical ventilation shafts. Open stairwell doors and apartment doors produce a pressure differential that accelerates airflow, therefore encouraging efficient cross ventilation all around the building. Particularly in hotter months, this natural ventilation system greatly increases thermal comfort and air movement. Fire safety rules, however, usually mandate that stairway doors stay closed, therefore stopping the flow of air. Consequently, inadequate cross ventilation in the summer months results in poor air circulation, which traps heat and moisture in indoor environments so lowering thermal comfort. Under such circumstances, the lack of enough ventilation leaves air conditioning as the only practical way to reduce heat, hence raising energy usage and reliance on synthetic cooling techniques.

Improving indoor ventilation to lessen dependency on air conditioning has become ever more crucial given the present energy crisis. Particularly their ventilation systems and opening design of the door and window, traditional dwellings design provide insightful ideas on how we may improve airflow in contemporary buildings.

Figure 2.24 Different airflow status in modern high-rise residential buildings

Source: Created by author, 2024

2.2. STRATEGIES FOR HVAC ENERGY SAVING AND CASE STUDIES

Before HVAC systems were common, Lingnan residents favored prioritized daylight over shading, even when the two conflicted. This preference is linked to the local summer rainy climate. In such a climate, poor interior lighting can increase humidity, promoting mold growth, a health risk.

Psychrometric Chart[12] for Guangzhou (Figure 2.25) was employed to evaluate the potential of passive strategies, which displays the relationship between temperature, humidity, and thermal comfort in this climate. The chart reveals that, **without any interventions, only 36.15% of the year falls within the ideal thermal comfort range.** In other words, without any cooling or ventilation measures, Guangzhou's climate naturally supports indoor comfort for just over a third of the year.

The percentage of the year that satisfies thermal comfort criteria rises dramatically to 83.09% by including passive strategies include trapping interior heat for use during cooler seasons and motivating inhabitants to run fans. This leap shows how well focused passive measures can preserve comfortable temperatures without depending just on air conditioning. However, **HVAC systems are needed during around 17% of the year since these methods by themselves cannot lower high temperatures and humidity to reach comfort.**

In view of this, the focus of this chapter is on exploring ways to lower the energy consumption tied to HVAC [13]usage. By some design strategies, the energy efficiency of air conditioning in Guangzhou's demanding climate can be optimized.

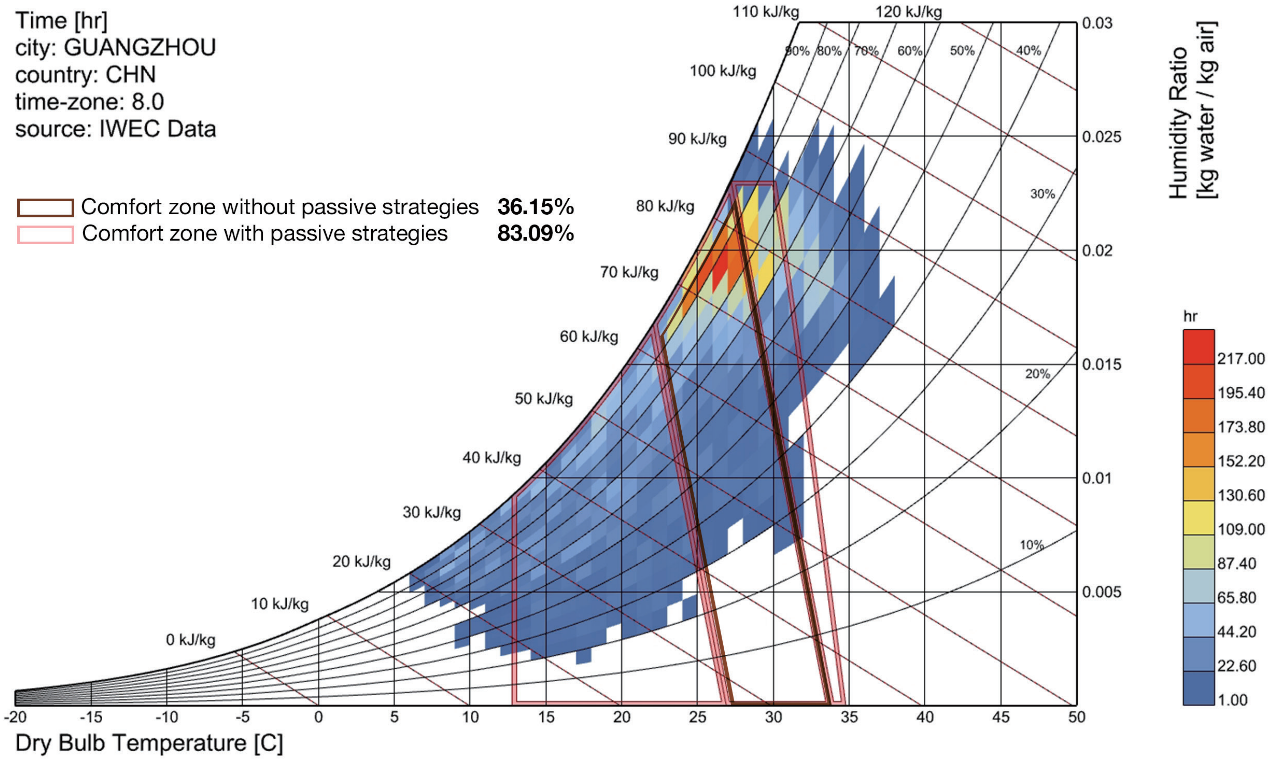
12 A psychrometric chart is a graphical representation of the thermodynamic properties of moist air at a constant pressure, typically corresponding to an altitude relative to sea level(Wikipedia contributors, 2024).

13 Heating, ventilation, and air conditioning (HVAC) is the use of various technologies to control the temperature, humidity, and purity of the air in an enclosed space. Its goal is to provide thermal comfort and acceptable indoor air quality. (DesignBuilder Software.2016)

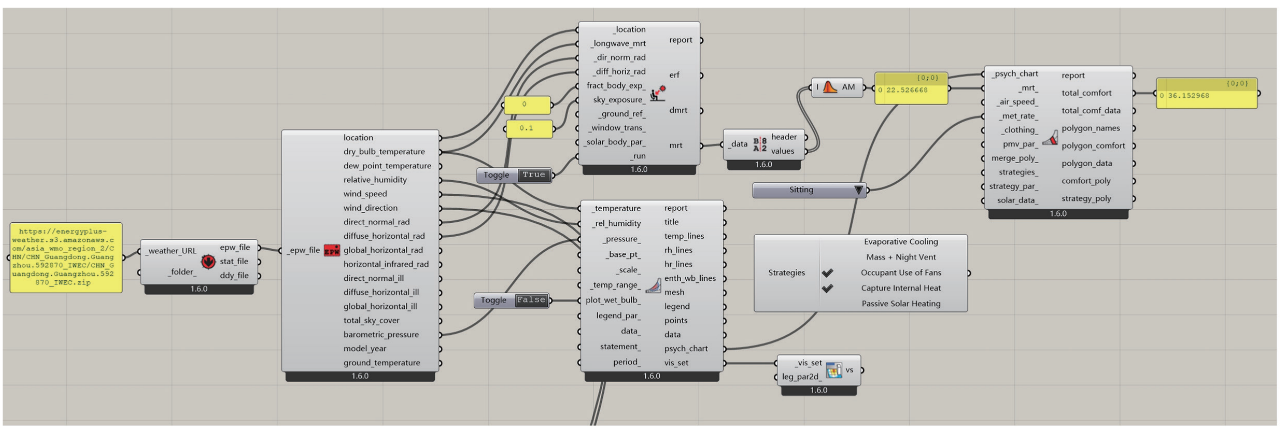
Figure 2.25 Psychrometric Chart and Indoor thermal comfort zone calculations in Guangzhou

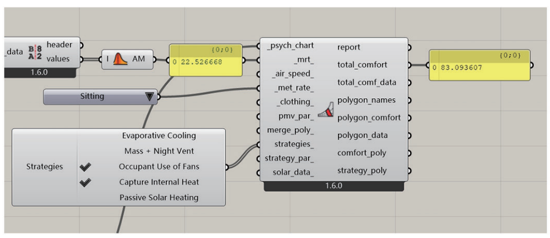
Source: Created by author, 2024

Software:Grashopper,Ladybug



Grashopper process of the Psychrometric Chart and Thermal comfort zone calculation





2.2.1 Commonly used cooling systems in Lingnan region

Summer downpours are frequent in the Lingnan region, and humidity there ranges from 70 to 90 percent. This makes it crucial to select an air conditioner with high dehumidifying capacity to maintain the comfort of indoor environments and avoid problems connected to moisture. Air conditioners naturally draw water out of the air while cooling. Like the condensation you see on a chilled glass in muggy weather, warm, humid inside air passes over the cool evaporator coils causes its temperature to drop and moisture condenses. The condensed water is then gathered and expelled outdoors. Air conditioners greatly reduce the interior relative humidity by always eliminating moisture.

For comfort and health, especially in humid regions like Lingnan[14], maintaining an indoor relative humidity of between 40–60% is desirable. For example, 25 ° C with low humidity seems colder than the same temperature with high humidity. Effective dehumidification of the air allows an AC to improve occupant comfort even in cases of somewhat low temperature.

Given the design focus on high-rise residential buildings, inverter split-system ACs and multi- split ACs are particularly well-suited for the Lingnan climate. These systems provide adaptable zone control, allowing residents to independently adjust cooling and humidity levels in different rooms, thereby enhancing comfort while optimizing energy use. Vari-speed compressors used in inverter ACs change their power output depending on cooling demand. Unlike non-inverter ACs, which run continuously switching the compressor on and off, inverter ACs progressively slow down or speed up the compressor to keep room temperature constant. The compressor slows down but does not totally off after the room achieves the target set temperature. This function helps the AC to keep temperature with little variations, therefore producing a more homogeneous interior space. (Figure 2.26)

Equipped with inverter technology, these ACs modify the compressor speed depending on real-time cooling needs, thereby providing reliable, silent, and energy-efficient cooling suited for the conditions of humid regions. Modern inverter ACs particularly help to balance humidity control and temperature control. Even with a slower compressor, inverter ACs can keep the evaporator coils at a lower temperature. This continuous cooling action lets the AC efficiently eliminate humidity from the air without appreciably lowering the room temperature.

14 The relative humidity in the Lingnan area during summer often ranges from 70% to 90%.

Figure 2.26 The difference between Inverter Acs and Non-inverter Acs

Source: Panasonic Australia Pty Ltd. 2024

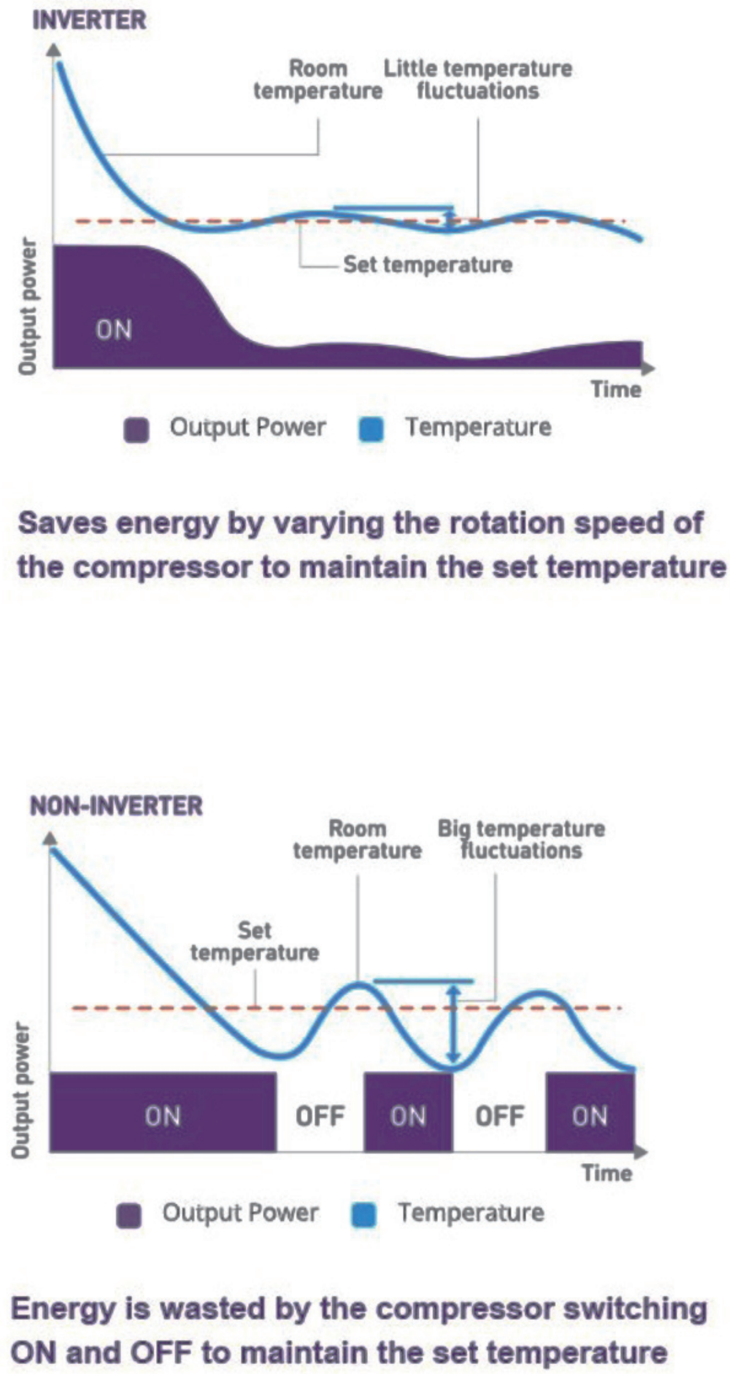
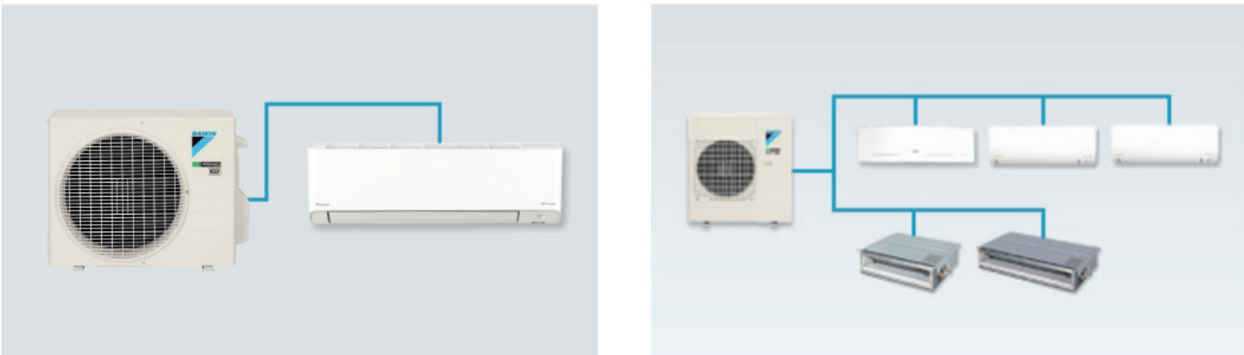


Figure 2.27 The impact of air conditioner outdoor units on building facade

Source: Huanqiu.com, 2022

Figure 2.28 The difference between Split Acs and Multi-split Acs

Source: DAIKIN INDUSTRIES, Ltd., 2024



Split

- Connects one indoor unit to an outdoor unit.
- Installs simply and unobtrusively to buildings with no need for ductwork.
- Delivers a sophisticated air conditioning solution to single zone interior spaces at an affordable price.
- Provides a simple solution for one-room additions.

Multi-split

- Connects up to five indoor units to a single outdoor unit.
- Installs a complete air conditioning system to multiple zone interior spaces with no need for ductwork.
- Provides individual control of room temperature settings.
- Enables indoor units of different styles and capacities in one system for customized solutions unique to each residential setting.

When selecting an air conditioning system, it is also important to consider the impact of outdoor units on the building façades. As shown in Figure 2.27, Since the air conditioner outdoor unit needs to be hung on the facade and placed on the roof, the number of air conditioner outdoor units will have a great impact on the facade design. As Figure 2.28 shows, the outside units of split and multi-split air conditioning systems vary greatly in size, capacity, and functionality to satisfy particular cooling needs. Small and meant to accommodate only one indoor unit, a split system outdoor unit is perfect for cooling particular rooms. Typically up to five, each with independent temperature control, a multi-split outdoor unit is larger and has a more powerful, variable-speed compressor to meet the combined cooling needs of several indoor units. For multi-room uses, this adaptability helps multi-split systems change output depending on the cooling needs of every room, hence increasing their efficiency.

The multi-split system connects multiple indoor units through one outdoor unit. Although it requires more complicated pipes, it reduces the space occupied by the exterior wall or balcony and maintains the integrity of the building facade. In contrast, the split system requires an outdoor unit for each indoor unit, which may affect the appearance of the building facade, especially when multiple rooms need to be cooled.

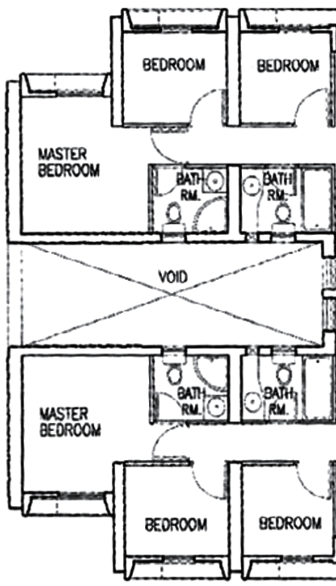
2.2.2 Shading Panels on Opaque Facades for Cooling Energy Reduction

In previous sections, we noted that frequent cloud cover in the Lingnan region during summer reduces the intensity of direct solar radiation, making window shading less critical. Instead, people prioritize natural lighting and visual comfort. In 2019, Sheng Liu and colleagues from The Chinese University of Hong Kong investigated adding shading panels to the opaque façades of high-rise public rental housing (PRH) buildings, which have high cooling demands due to Hong Kong's hot, humid climate and urban heat island effect, to improve energy efficiency.

The study focused on the "Concord" building type[15] (Figure 2.29) which has been used in most recent public rental housing projects in Hong Kong. Using DesignBuilder software[16] with the EnergyPlus engine, the researchers simulated different horizontal and vertical shade panel configurations by altering three key parameters: tilt angle, panel length, and separation (Figure 2.30). Their aim was to investigate how, especially for west-facing façades with maximum solar gain, shade optimization might reduce the summer cooling energy use (Sheng Liu and others, 2019).

Figure 2.29 Floor plan of Conc

Source: Sheng Liu, et al. 2019



15 the Concord type PRH (public rental house) building has been chosen as the subject for case study. It represents the typical form of residential buildings in Hong Kong and is prevalent among the latest PRH estates as well as those now being constructed (Sheng Liu, et al. 2019).

16 DesignBuilder is an EnergyPlus based software tool used for energy, carbon, lighting and comfort measurement and control (DesignBuilder Software. 2016).

cord type PRH

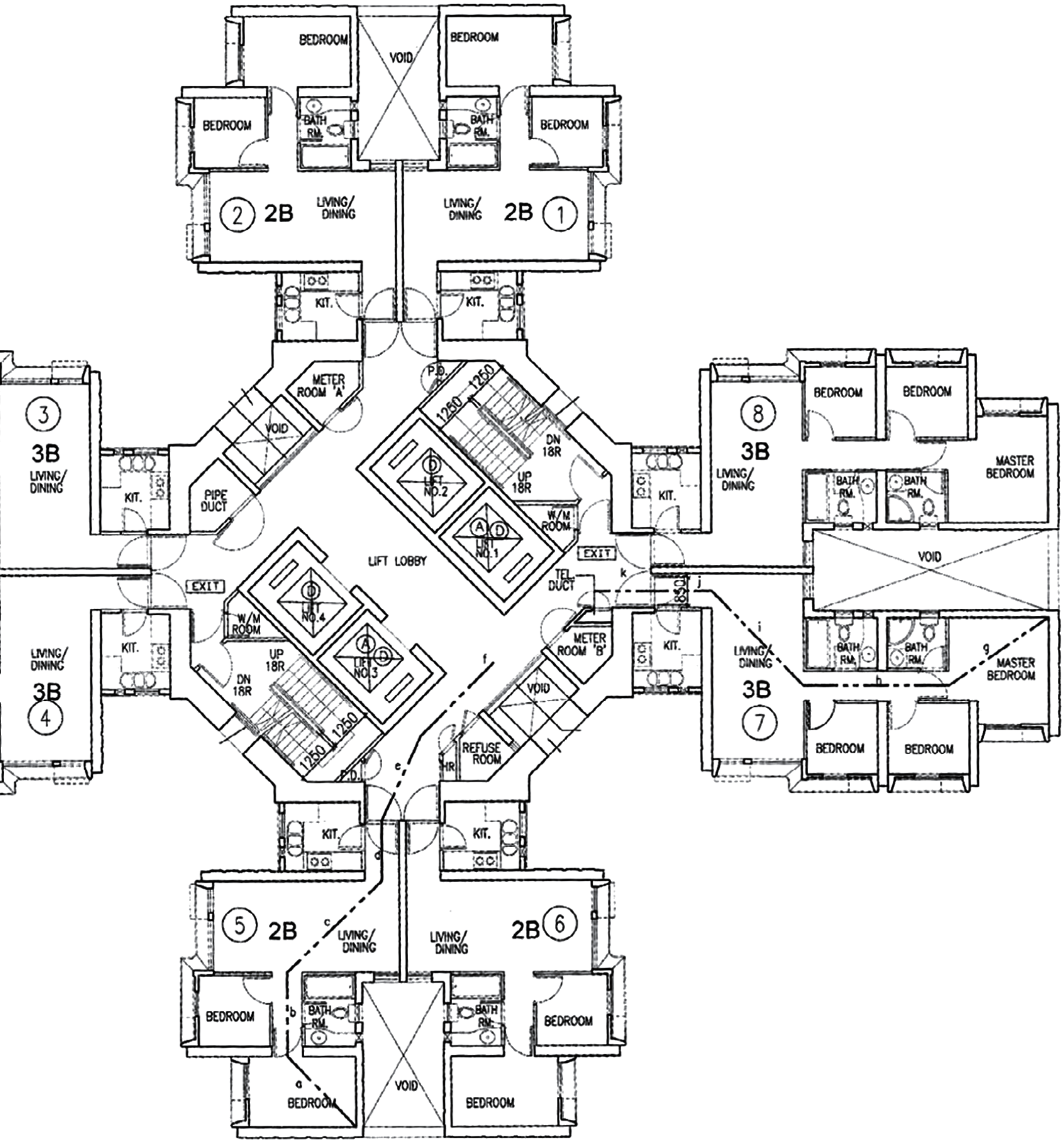
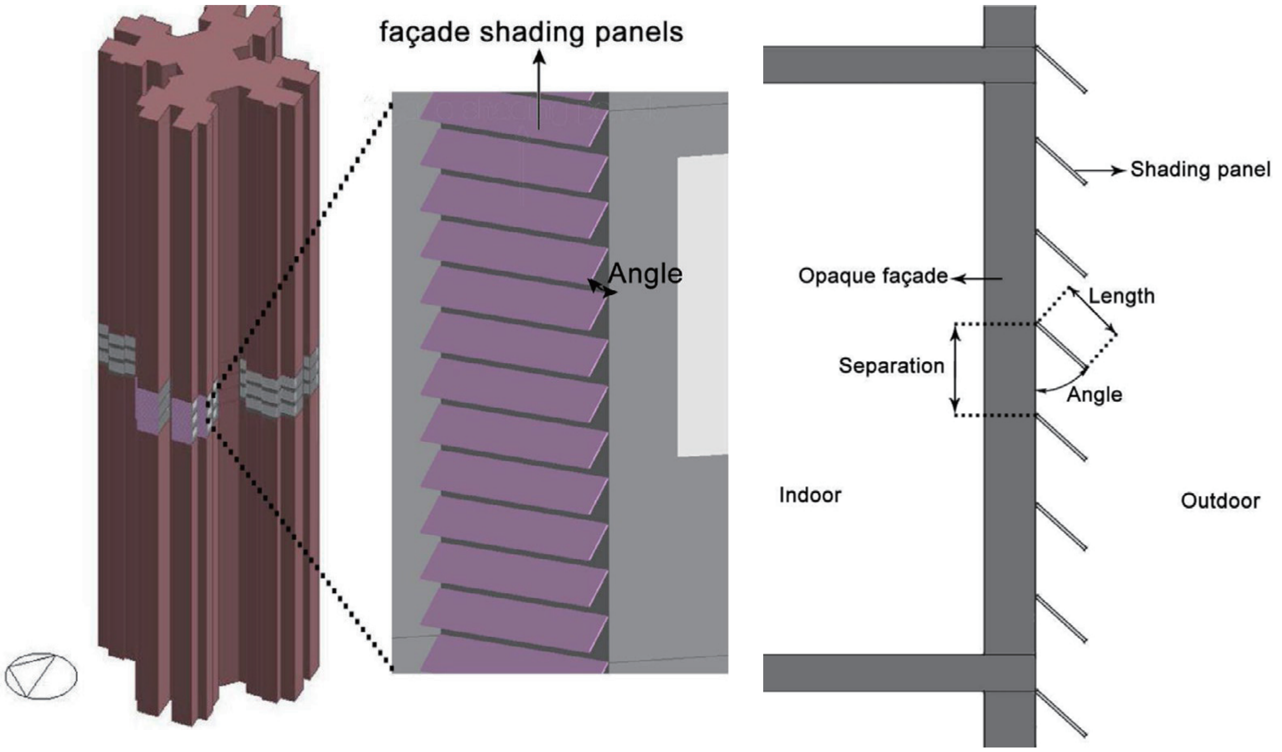


Figure 2.30 Simulation model and Input parameters of shading panels for the simulation.
Source: Sheng Liu, et al. 2019

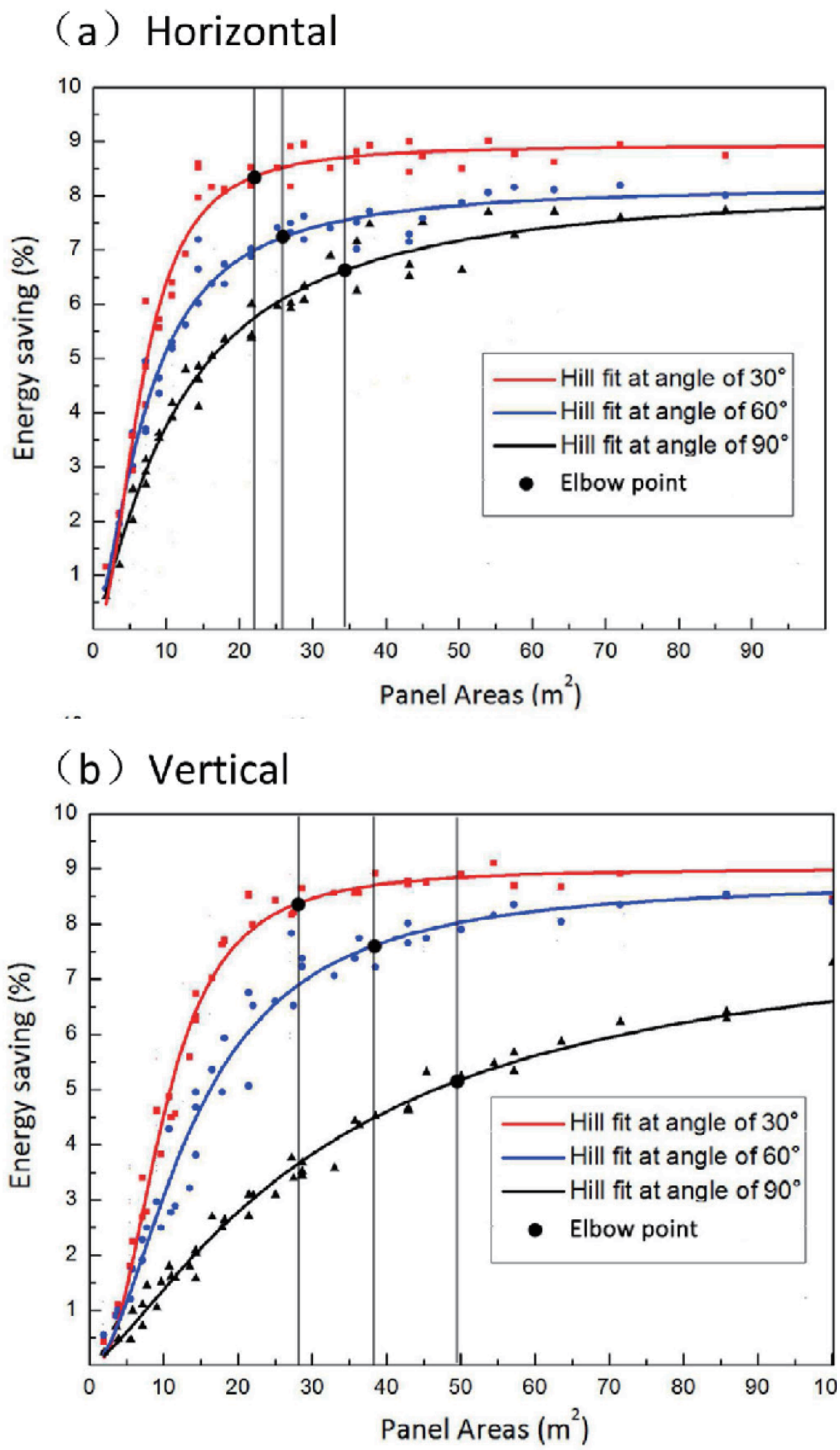


Though this design feature hasn't been put into practice yet—so there's no real-world data to back up these findings—initial tests suggest that west- and southwest-facing facades respond most sensitively to shading. Once a certain number and length of shading panels are installed, the energy savings[17] begin to level off. As shown in Figure 2.31, for west-facing facades, shallower angles (like 30 °) can effectively block the sun while using less material, leading to the highest energy savings. Specifically, at a 30° tilt, both horizontal and vertical panels can achieve around an 8.6% reduction in energy use, while at 90°, horizontal panels only save about 6.8% and vertical panels just 5.2%. Putting these optimal shading setups into practice could significantly enhance the energy efficiency of high-rise public rental housing (Sheng Liu, et al. 2019).

17 Energy savings are expressed as a percentage reduction from the base model without any shading.

Figure 2.31 Scatter plots (dots) and hill regressions (curves) for (a) horizontal and (b) vertical shading panels

Source: Sheng Liu, et al. 2019



2.2.3 Balancing energy and daylighting performances of transparent façade

In earlier discussions on Changshi Xia's shading system, it was noted that before HVAC systems became widespread, people in the Lingnan region prioritized daylight over shading, even when the two conflicted. This preference is closely related to the local climate, characterized by frequent summer rain. In such a climate, inadequate lighting in indoor environments can lead to higher humidity, therefore providing ideal circumstances for mold development—a hazard for human health.

With the advent of air conditioning, a new method for indoor dehumidification became available. However, these two approaches work depending on essentially different ideas. Apart from lighting interior areas, daylight influences photometry and radiometry by means of solar heat gains that increasing the cooling load of a building. One major architectural difficulty has become the balance between effective daylighting and energy use. **Although the use of natural light reduces the need on artificial lighting, it also increases solar heat gain in the room, which affect the energy needs of heating, ventilation, and air conditioning (HVAC) systems.**

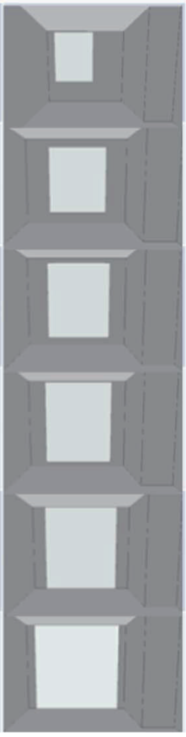
Building on this background, we may draw on the Hong Kong research by Jingchao Xie et al. on how best to use optimal envelope design to strike a compromise between energy usage and natural daylighting in tall residential structures. Two important metrics—average daylight autonomy (Ave. DA300)[18] to ascertain tenants' luminous comfort and Energy Daylight Rate (EDR)[19], a novel index combining lighting and cooling energy with daylight performance. The researchers assess several design concepts that strike a compromise between energy economy and visual comfort by applying these criteria. (Jingchao Xie et al. 2017)

18 Ave. DA300 aggregates daylight autonomy (DA) values throughout a space or region to determine its ability to satisfy a 300-lux requirement. This metric improves on spatial daylight autonomy (sDA), which measures the percentage of occupied space that reaches target illuminance for at least 50% of the time. Ave. DA300 represents both cumulative daylighting performance and spatial luminous comfort for residents (Jingchao Xie et al. 2017).

19 Energy Daylight Rate (EDR) is a proposed parameter that evaluates the relationship between daylighting performance and total energy consumption, considering both artificial lighting and cooling loads. It is calculated using the formula: Energy Daylight Rate=Total energy/ΔDA300, The EDR can yield both positive and negative values. EDR > 0: An increase in daylighting performance leads to increased total energy consumption; EDR < 0: An increase in daylighting performance results in decreased total energy consumption.(Jingchao Xie et al. 2017)

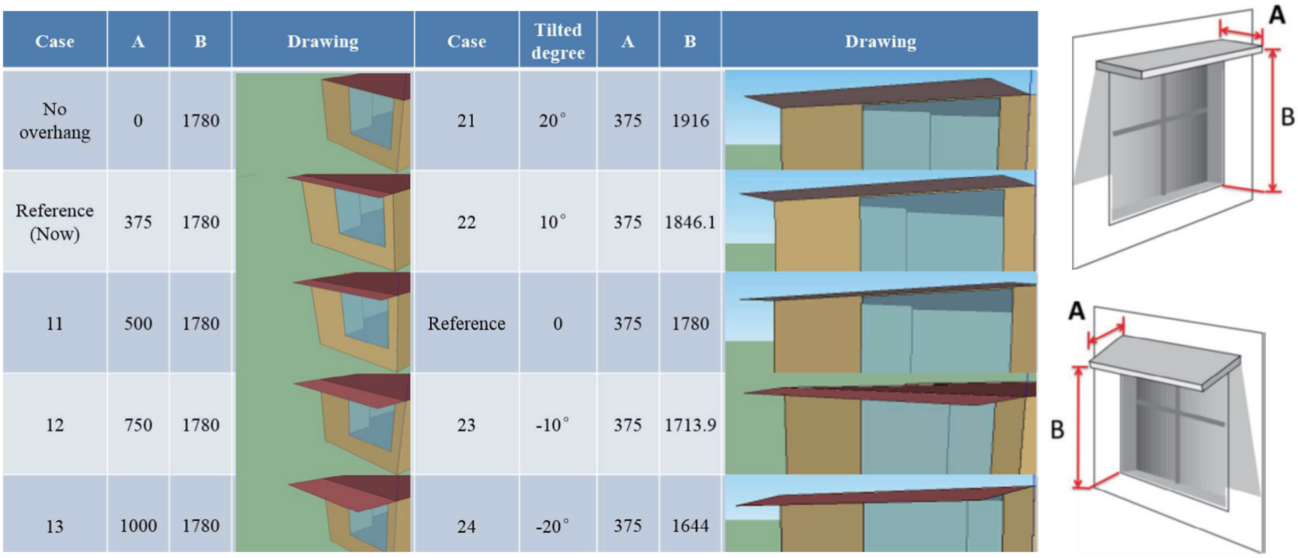
Figure 2.32 Cases of window openings with different dimensions (unit: m).
Source: Jingchao Xie et al. 2017

Case	Height	Width	WWR	WFR	Drawing	Case	Height	Width	WWR	WFR	Drawing
Reference	1.755	1.405	0.3544	0.1263		Reference	1.755	1.405	0.3544	0.1263	
1	1.979	1.584	0.4505	0.1606		6	0.820	0.820		0.1608	
2	2.188	1.751	0.5507	0.1962		7	1.170	1.170		0.1964	
3	2.378	1.904	0.6508	0.2319		8	1.435	1.435		0.2318	
4	2.530	2.063	0.7502	0.2673		9	1.659	1.659		0.2673	
5	2.530	2.338	0.8502	0.303		10	1.858	1.858		0.3031	



The study focuses on public housing units, as a case study for evaluating the balance between energy consumption and daylighting performance. They constructed detailed digital models using Daysim for daylight simulation and EnergyPlus for energy performance analysis. The experiment examined 96 unique cases across several variables: floor levels, unit orientations (north, south, east, west), building distances (15m, 25m, and 35m), and the units' position within the building (inner or outer ring). The authors tested a range of envelope configurations, including variations in window size (as shown in Figure 2.32, comparing primary window enlargement with secondary window addition) and shading devices (as shown in Figure 2.33, examining different lengths and tilt angles of overhangs), to observe their effects on both daylighting and cooling load. (Jingchao Xie et al. 2017)

Figure 2.33 Cases of overhangs with different dimensions (units: mm).
Source: Jingchao Xie et al. 2017

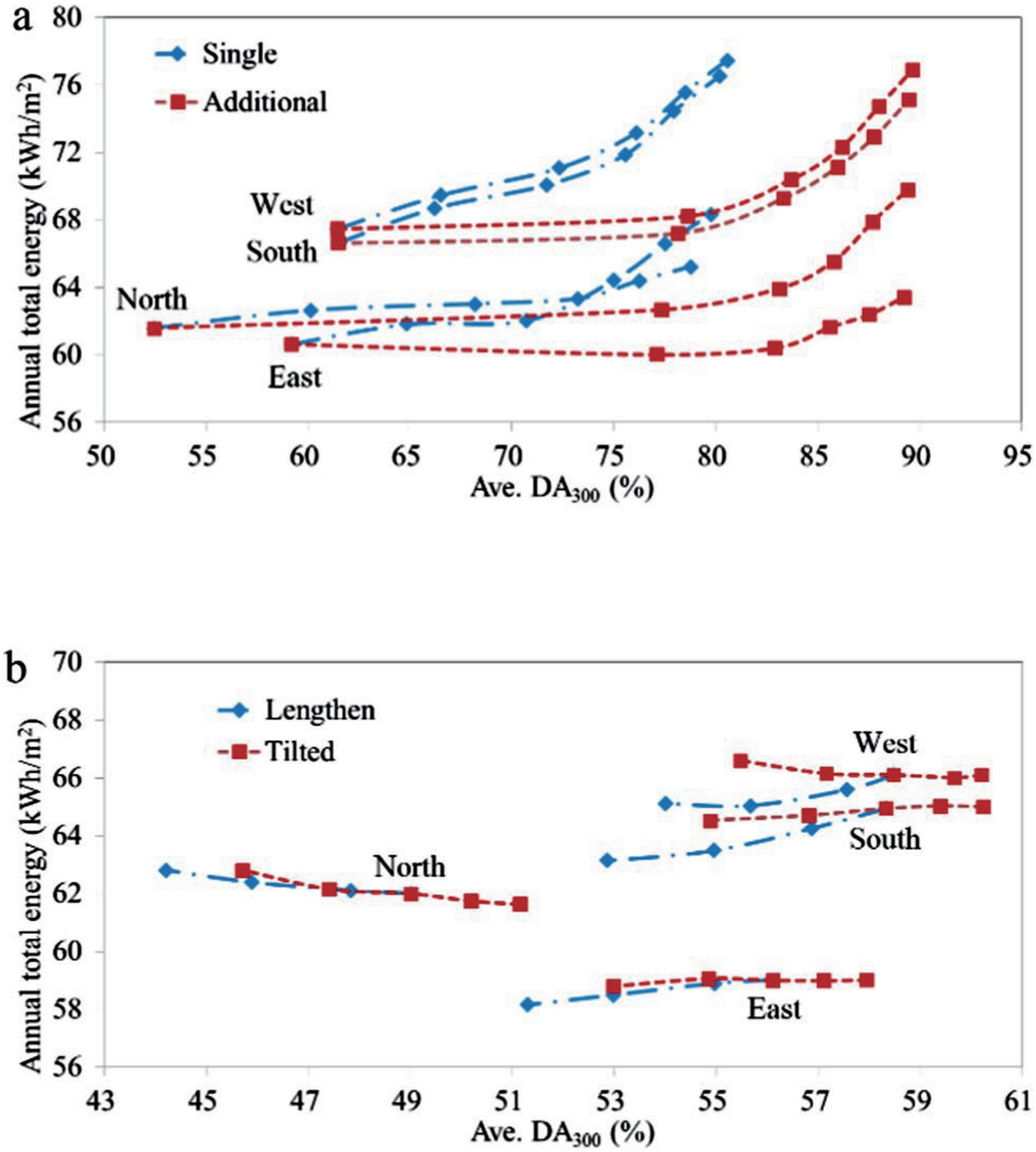


Case	A	B	Drawing	Case	Tilted degree	A	B	Drawing
No overhang	0	1780		21	20°	375	1916	
Reference (Now)	375	1780		22	10°	375	1846.1	
11	500	1780		Reference	0	375	1780	
12	750	1780		23	-10°	375	1713.9	
13	1000	1780		24	-20°	375	1644	

Based on the simulation results (Figure 2.34), the study demonstrates that orientation plays a significant role in both daylighting and energy use. **Units facing west and south consistently show higher values of Ave. DA300 and consume more AC energy due to increased solar heat gain,** while **north-facing units exhibit the lowest Ave. DA300 values. East-facing units use the least annual lighting energy**. (Jingchao Xie et al. 2017) Additionally, **adding a secondary window is more effective than enlarging the primary window, as it provides sufficient daylight with minimal impact on cooling needs** (Figure 2.34, a). **Lengthening shading overhangs is also more effective than adjusting their tilt**, as it effectively blocks solar heat gain without significantly reducing indoor light levels (Figure 2.34, b). **However, adopting an external shading system for north-facing units actually increases lighting energy consumption, and even total energy consumption, due to limited daylight.** For these units, internal shading is recommended rather than external shading elements in the envelope design. (Jingchao Xie et al. 2017)

Figure 2.34 EDR (slope) in all orientations: (a) window opening scenarios; (b) overhangs shading scenarios

Source: Jingchao Xie et al. 2017



Chapter 0.3

Climate-Adaptive Retrofit Design for High-Rise Buildings in Lingnan region

3.0. SITE ANALYSIS

3.0.1 Historical background

As previously mentioned, China has a significant number of high-rise buildings. Many of the earliest high-rises in the country have now reached the stage where updates and renovations are necessary. This case study focuses on the case of the Guangzhou Hotel (Figure 3.0.0), located in the northeast corner ofHaizhu Square[20] iin the central area of Guangzhou. The hotel has a total construction area of 32,096 square meters and comprises a 27-story main building, a 5-story west wing, and a 9-story north wing. Construction began in early 1966 and was completed in April 1968, with a total duration of 27 months. (Guangzhou Urban Planning Department Design Team,1969)

Built during the Cultural Revolution, the Guangzhou Hotel is among China's highest skyscrapers erected following independence. Its main purpose was to host foreign visitors visiting the China Import and Export Fair in Guangzhou. Having opened 56 years ago in 1968, the hotel needs renovation and modernizing to fit modern needs. In October 2020, the hotel's management commenced an interior restoration, and the refurbished facility officially reopened on January 26, 2022. This restoration involved a deviation from conventional hotel business strategies by integrating shared office space.

According to previous surveys, office building vacancies in the region are around 23%. The city's development trajectory and the relocation of the China Import and Export Fair venue amid urban renovation have also harmed the hotel business model. Under these conditions, I recommend transforming the hotel without consideration to Chinese land use restrictions.

20 Haizhu Square is located at the intersection of Guangzhou Qiyi Road, Yide Road and Taikang Road in Yuexiu District, Guangzhou, China, covering an area of 35,000 square meters. It is the intersection of the central axis of Guangzhou's old city and the riverside landscape belt. It is currently the only riverside square in Guangzhou. (Wikipedia contributors, 2025)

Figure 3.0.0 Historical photos of Guangzhou Hotel

Source: Guangzhou Municipal Housing and Urban-Rural Development Bureau et al. 2018

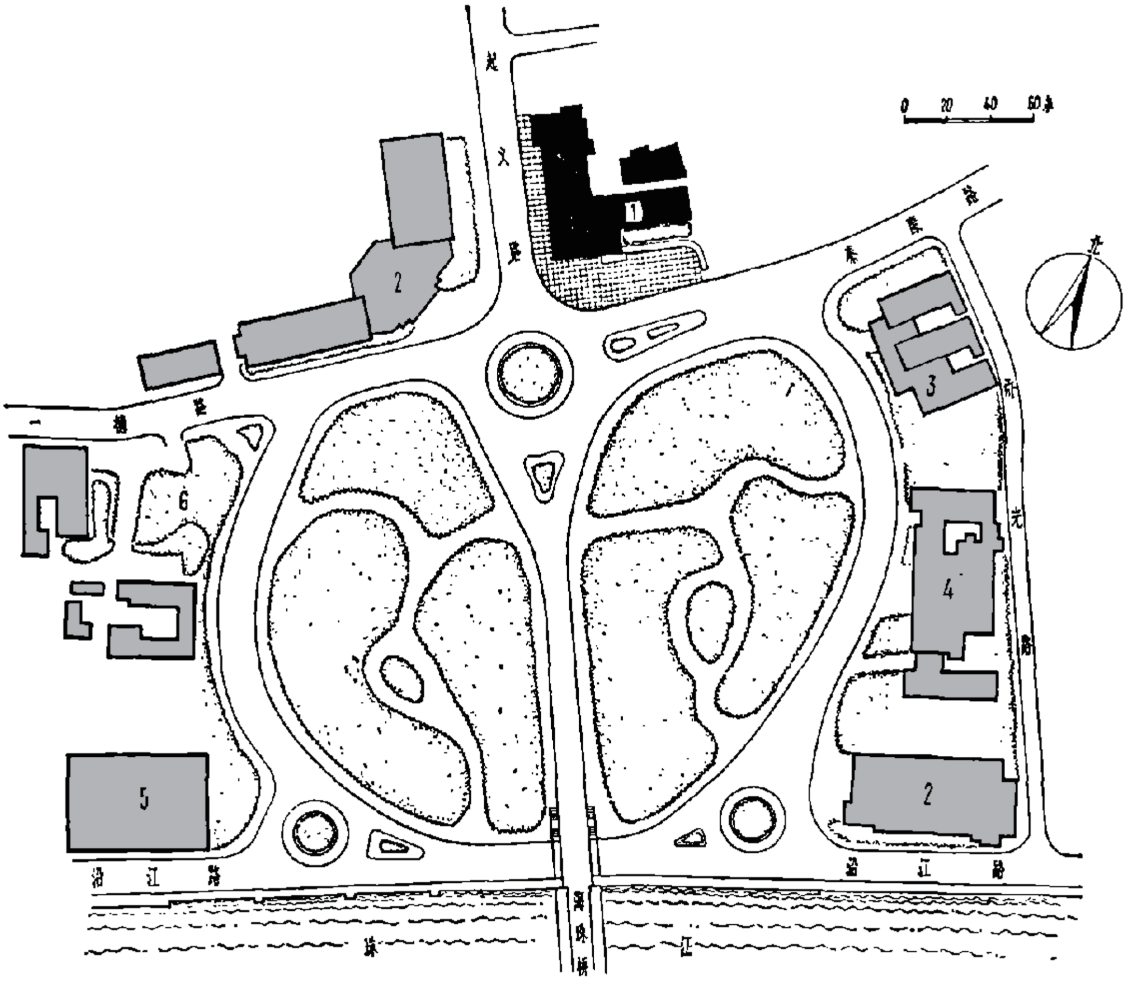
https://zh-yue.wikipedia.org/wiki/%E5%BB%A3%E5%B7%9E%E8%B3%93%E9%A4%A8

https://zfcj.gz.gov.cn/zjdt/ztzl/ygdzt/gzslsjzygd/lyjz/content/post_2581249.html

http://www.seelvyou.com/html/scenic/guangdong/guangzhou/2013/0421/891_4.html

Figure 3.0.1 Historical Master Plan of Guangzhou hotel in 1969

Source: Guangzhou Urban Planning Department Design Team,1969



①广州宾馆; (Guangzhou Hotel)

②中国出口商品交易会; (China Import and Export Fair)

③侨联大厦; (Qiaolian Building)

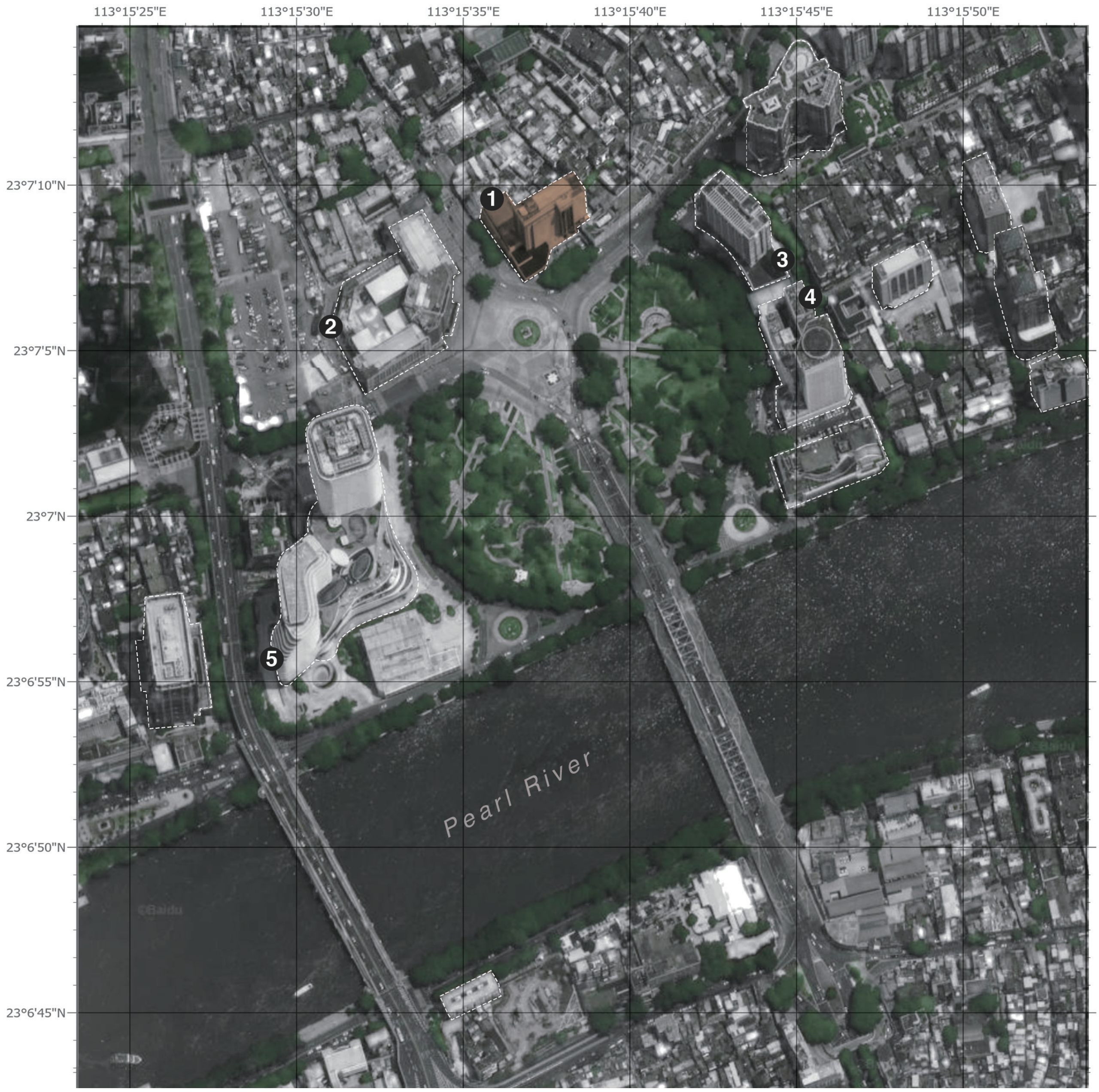
④华侨大厦; (Huaqiao Building)

⑤五仙門电厂; (Wuxianmen Electric Factory)

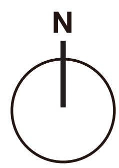
⑥誼园 (Garden)

Figure 3.0.2 Site Plan of Guangzhou hotel in 2024

Source: baidu map, 2024

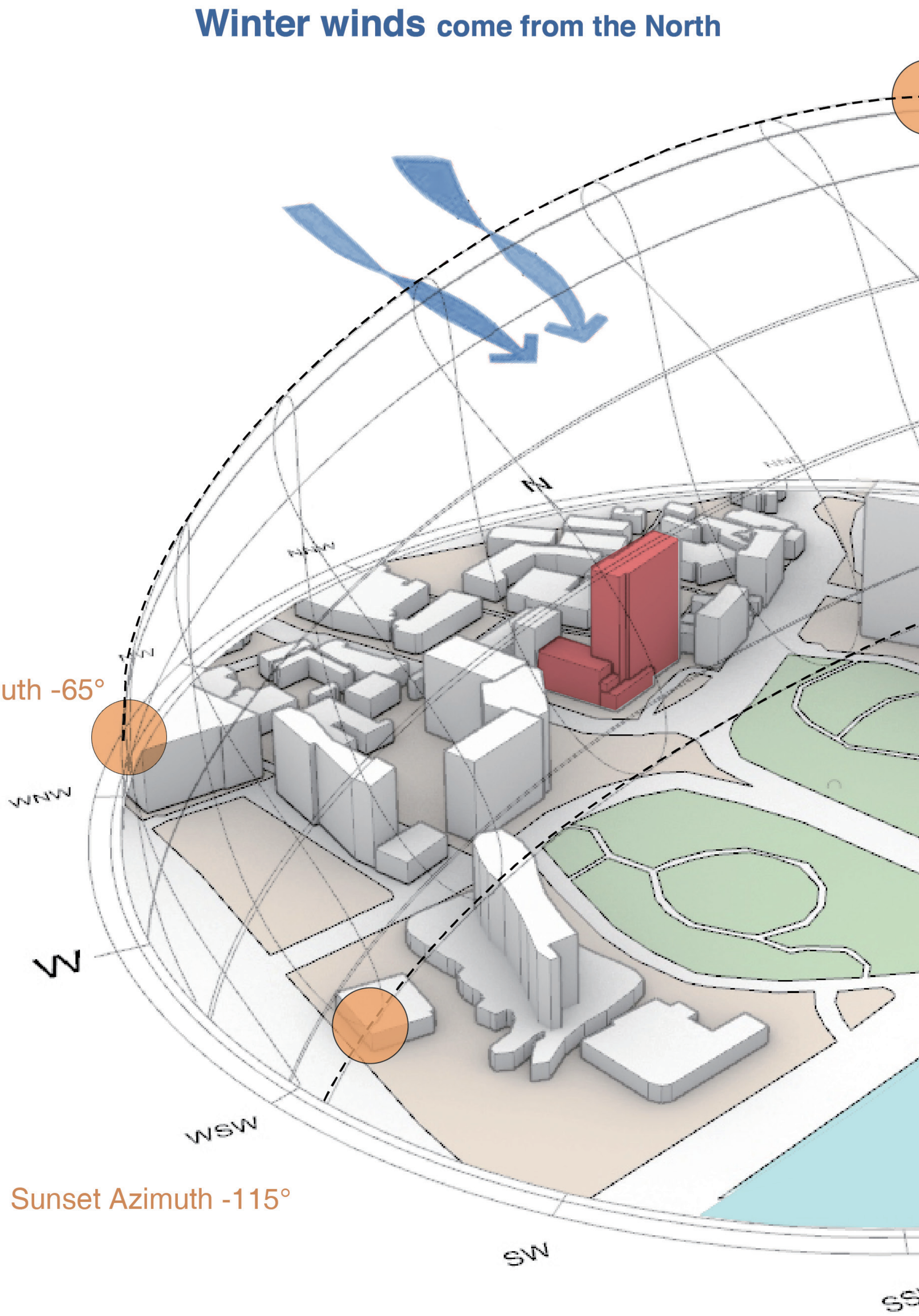


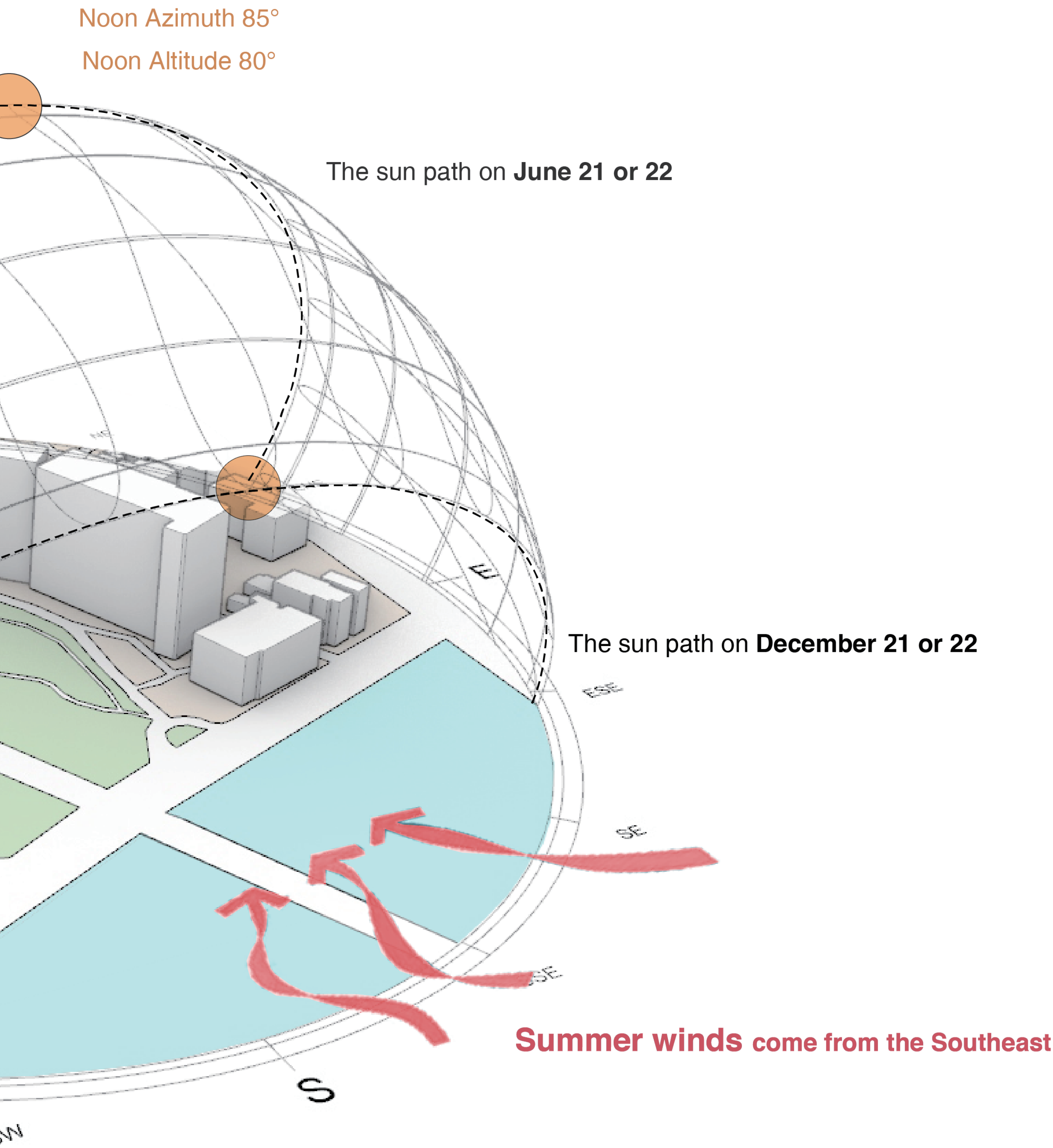
1. Guangzhou Hotel
2. Commercial Center
3. Wanyi Plaza Office Building
4. Huaqiao Building
5. Star International Business Center



3.0.2 Environmental analysis

Figure 3.0.3 Site Analysis of Guangzhou hotel
Source: Created by author, 2024





Noon Azimuth 85°
Noon Altitude 80°
The sun path on **June 21 or 22**
E
The sun path on **December 21 or 22**
ESE
SE
SSE
S
SW
Summer winds come from the Southeast

3.1. RETROFIT DESIGN PROPOSAL

The objective of this retrofit is to revive the structure, converting it into a paragon of sustainability and harmony with its environment. **The goal was to design a building that would perform its function, adapt to social development requirements, minimize reliance on energy-consuming HVAC systems** and comply with sustainable building principles.

The building was split in two primary zones in order to realize this concept. From the first to the fifth stories, **the lower levels stay committed to its existing hotel function**. But this area has been transformed with great intention: it will provide comfort and peace to patients from the surrounding hospital and their families, therefore offering them refuge during difficult times. Here, HVAC systems keep guarantees of a regulated and comfortable environment, tailored to meet the needs of these temporary visitors with economy and care.

The upper floors were extensively renovated. The existing building's framework is used(Figure 3.1.2) to c**onvert these high-rise floors into apartments to meet the region's apartment demand** to reduce embodied carbon emissions and following the layout of local bamboo houses optimize natural ventilation. These design changes lowered HVAC system dependence, which decrease operational carbon emissions and created healthier, more energy-efficient apartments.

The refurbishment aimed at addressing the building's underutilization, a problem intensified by the decreased demand for nearby hotels after the relocation of the Canton Fair Exhibition Center. To avert obsolescence, the design reconfigured the building as a dynamic, multifaceted place that caters to the community. The new concept implements a mixed-use strategy that integrates residential, hotel, and restaurant purposes.(Figure 3.1.0)

Figure 3.1.0 Function Analysis

Source: Created by author, 2024

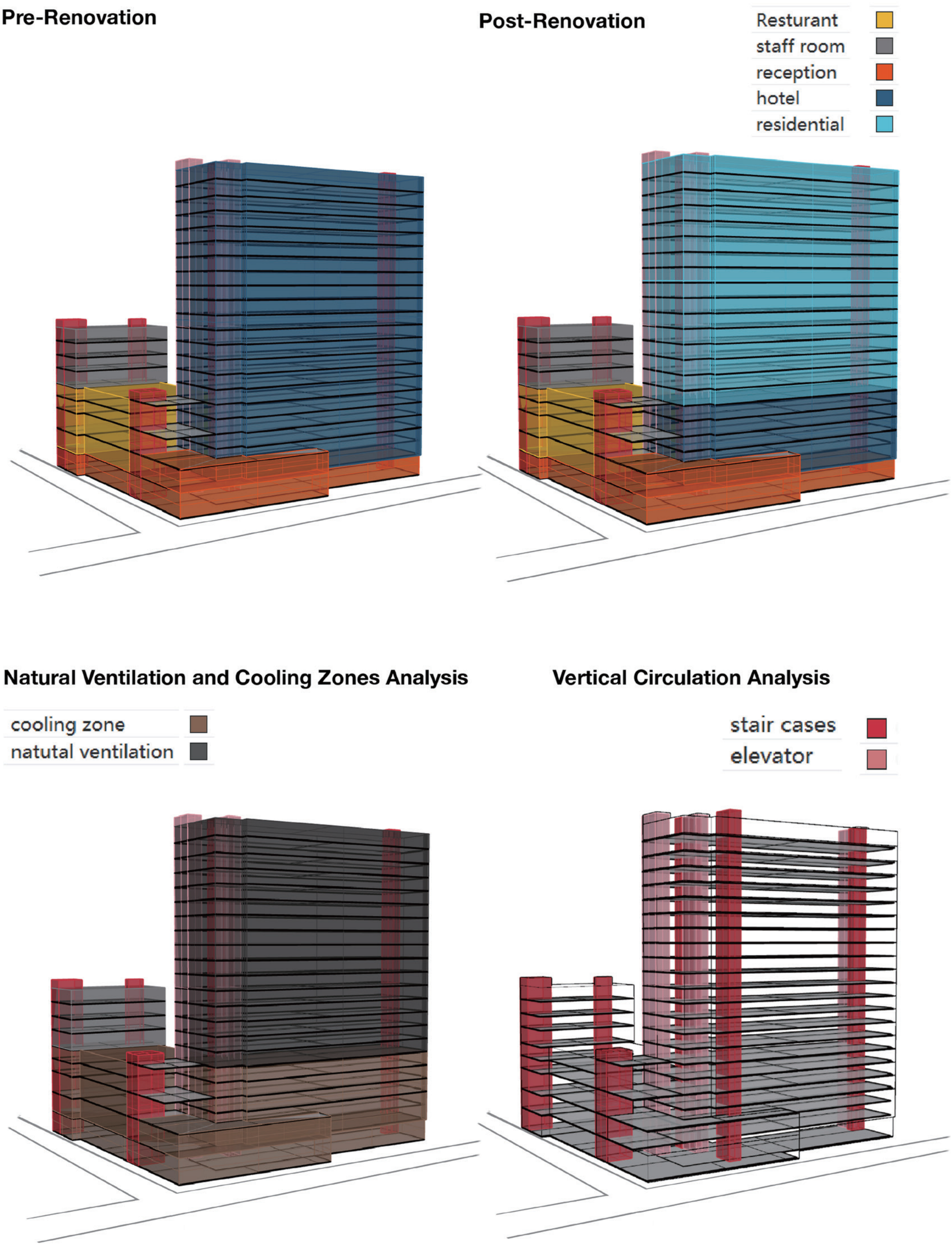


Figure 3.1.1 Existing hotel typical floor plan
Source: Guangzhou Urban Planning Department Design Team,1969
Unit:cm

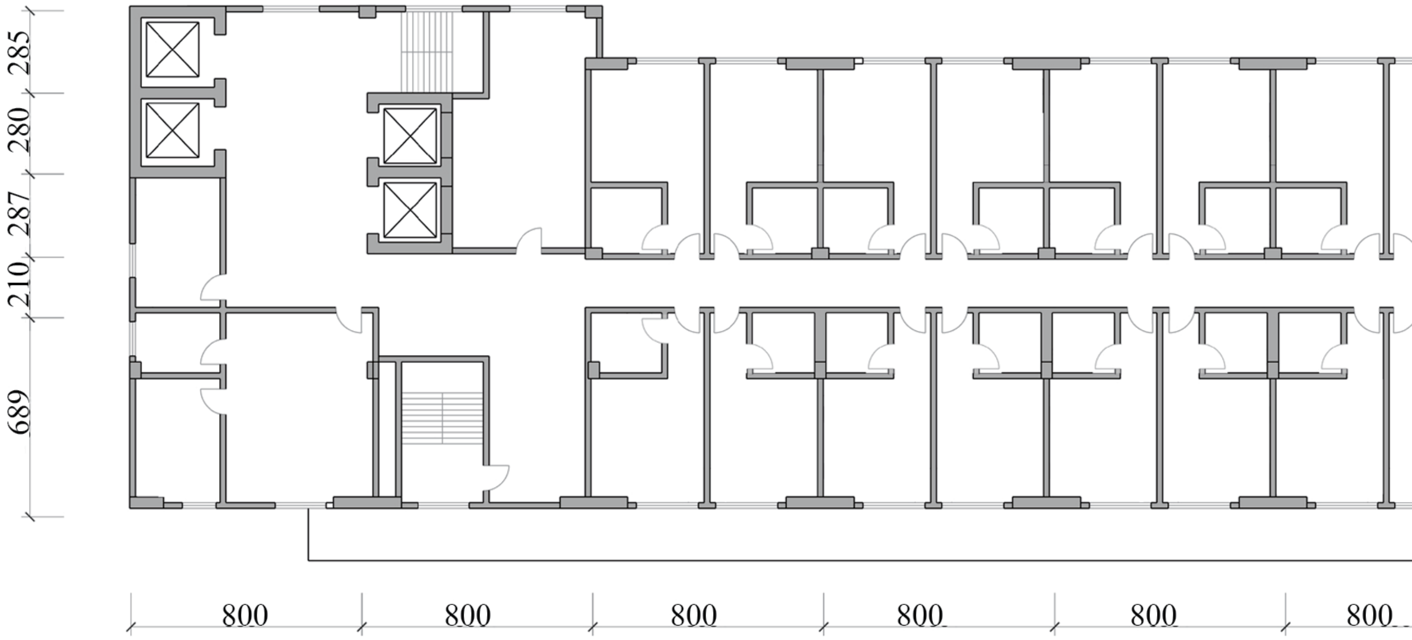
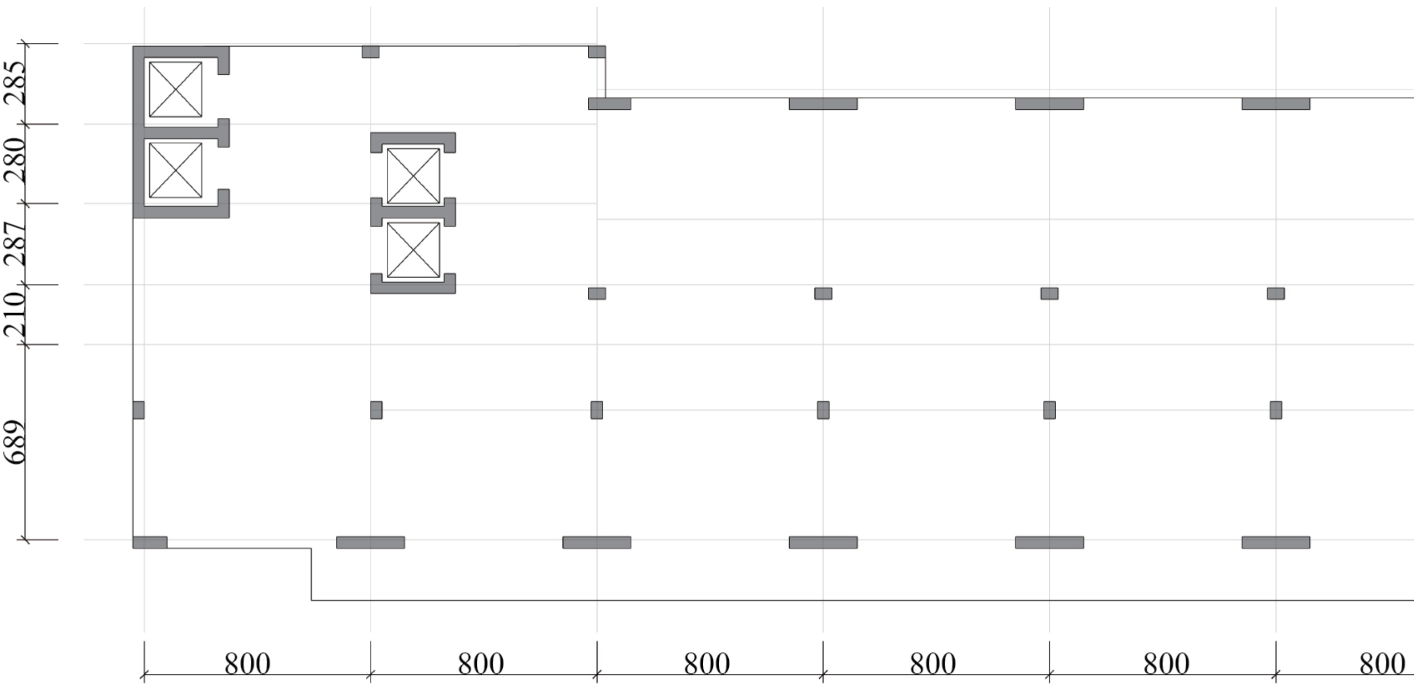
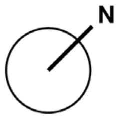


Figure 3.1.2 The structure plan of the existing building
Source: Created by author, 2024
Unit:cm





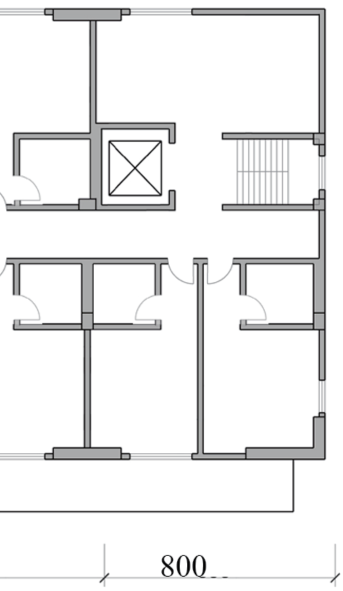
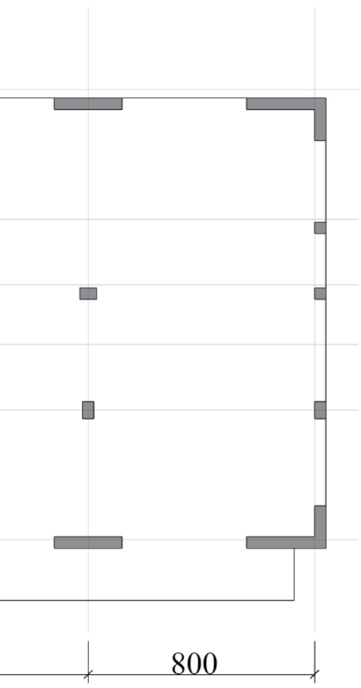


Figure 3.1.3 The structure model of the existing building
Source: Created by author, 2024



3.1.1 Layout design of the unit

The design strategy follows Aladar and Victor Olgyay's organized method, which prioritizes building layout before architectural design. I studied the functions of different living spaces inside the existing framework. Figure 3.1.4 shows that **the living room has the greatest occupancy length and relies most on natural light, while the bedroom has the least. Orienting the living room toward the southeast could maximize the daylight.**

I also assessed the needs of different residential spaces in terms of daylight, natural ventilation, noise control, and HVAC systems (Figure 3.1.5). **The bedroom**, which is primarily used for sleeping, **has the highest demand for noise control.** Since nighttime ventilation through open windows is usually impractical, the bedroom heavily relies on HVAC systems. It's advisable to refrain from locating the bedroom on the west and south sides. In contrast, **both the dining area and the living room have rather high - level demands for sunlight exposure and natural air circulation.** To cope with this situation, it is of great necessity to plan the spatial arrangement in accordance with the direction of the southeast summer monsoon. By doing so, a ventilation channel can be formed through these two spaces to boost the air circulation.

Based on the 8-meter column spacing of the existing building construction, Figure 3.1.6 depicts our unit layout designs. Every scheme was tested for wind-driven ventilation, particularly in summer when most needed. After plenty study, **I selected a final layout that it both took advantage of the higher wind speeds in high-rise residential buildings compared to low-rise structures and maximized cross ventilation in the indoor space.** This design typically makes benefit from natural ventilation to enhance interior air circulation and preserve suitable living conditions.

Figure 3.1.4 Analysis of the Degree of Sunlight Needs In Different Living Spaces Based on Daily Usage

Source: Created by author, 2024

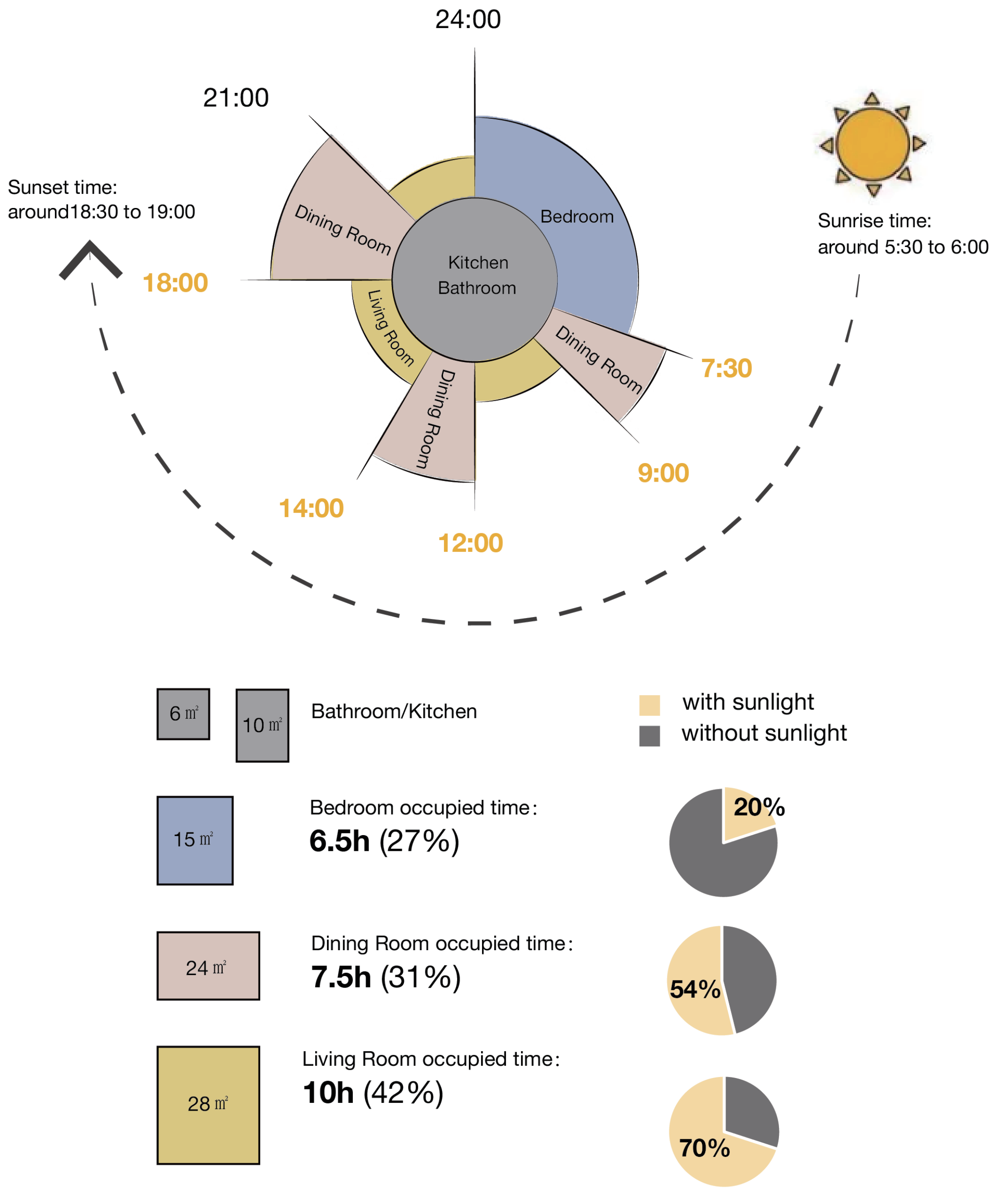
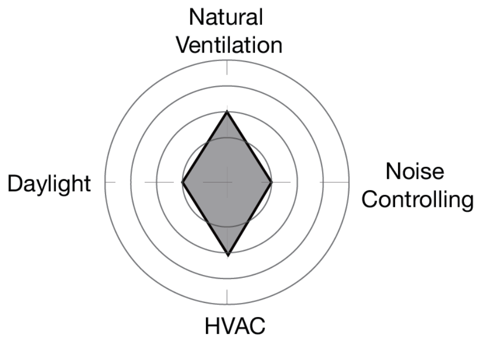


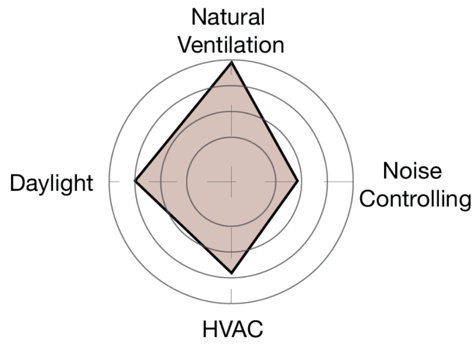
Figure 3.1.5 Optimal Orientation Analysis for Residential Spaces

Sources: Created by author, 2024



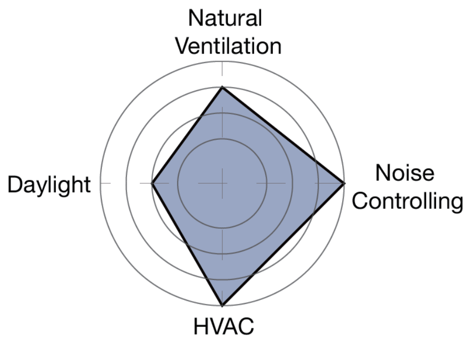
Bathroom/Kitchen:

Because people spend relatively short periods of time in kitchens and bathrooms, **mechanical ventilation systems** can be installed to ensure proper airflow when adding windows is not feasible due to space constraints.



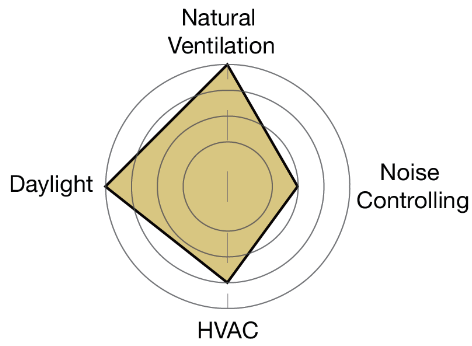
Dining Room:

To optimize natural ventilation in the dining room, it is ideal to place it **in the southeast** to benefit from prevailing summer winds.



Bedroom:

Since controlling environmental noise is essential for sleep, natural ventilation can be challenging to achieve. Therefore, the bedroom relies more on the HVAC system for ventilation. Placing the bedroom **on the north or east side** can help reduce energy consumption.

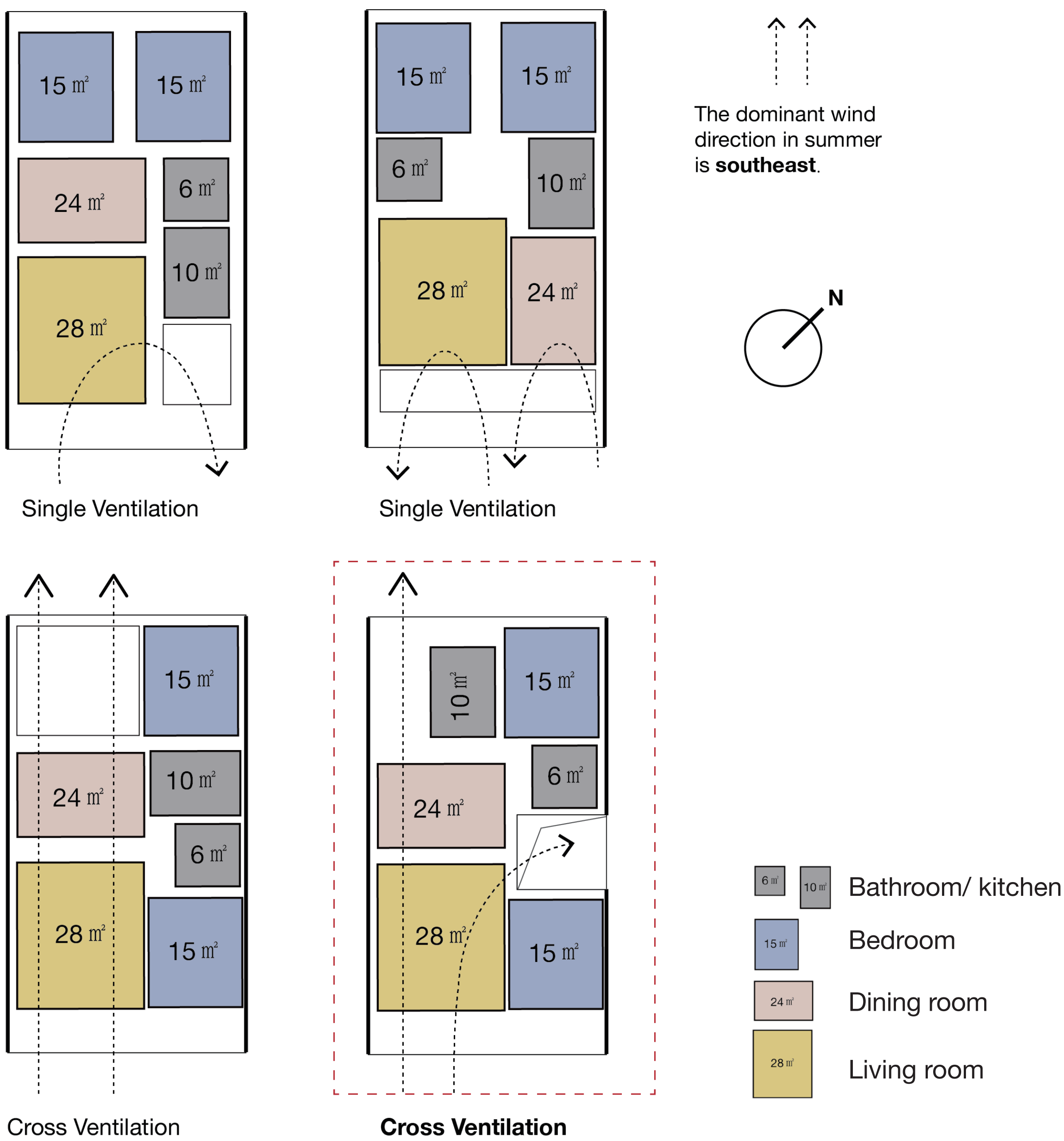


Living Room:

To maximize natural light, the living room is best positioned **facing east or south**, which helps reduce the need for artificial lighting. Additionally, since the living room typically has a larger area, it is ideal to utilize natural ventilation for cooling the space, minimizing air conditioning usage, and thereby reducing energy consumption.

Figure 3.1.6 Wind-Driven Ventilation Analysis in summer for Different Residential Space Combinations
Sources: Created by author, 2024

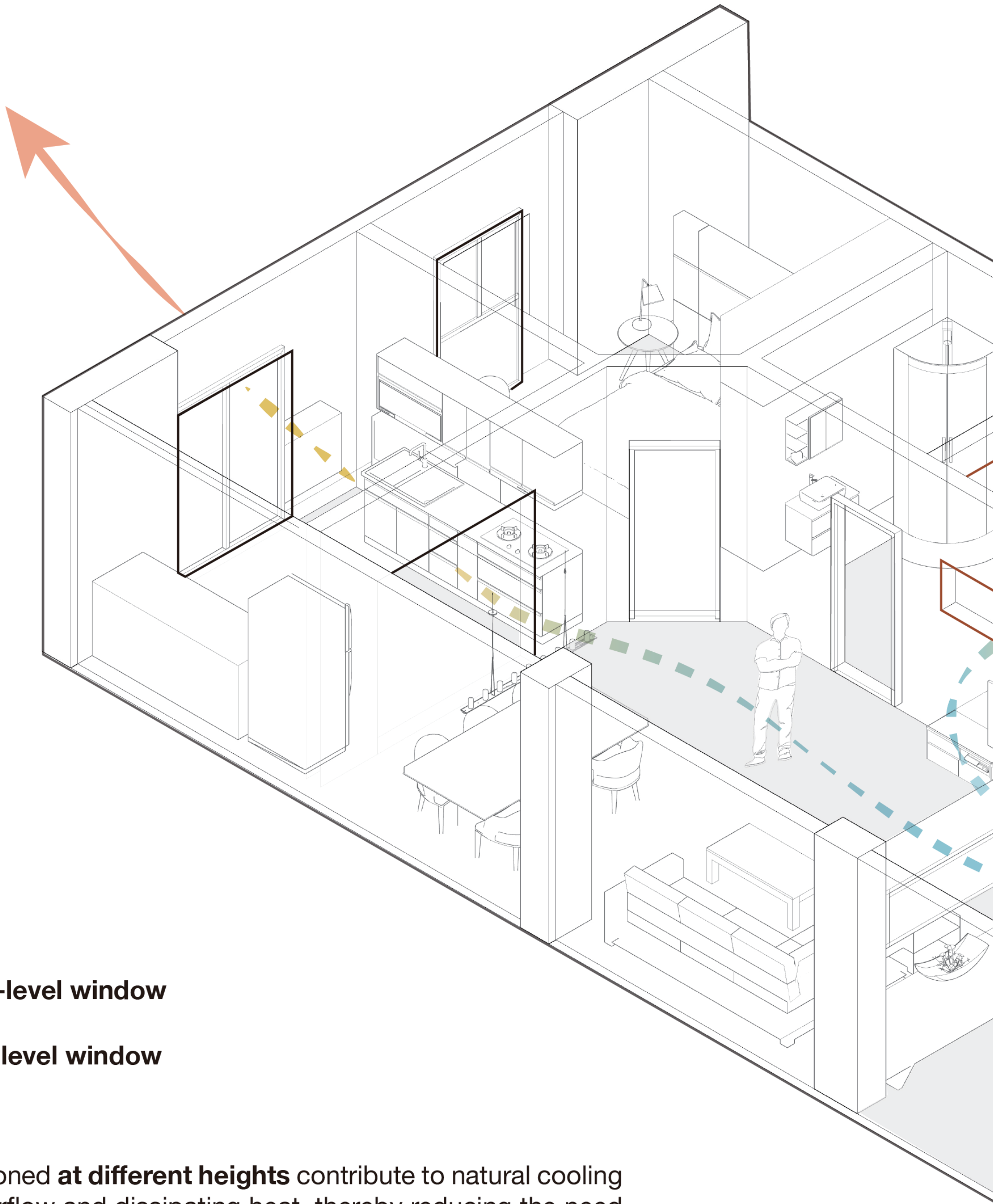
In China, the typical family structure consists of two parents and one child, and two-bedroom apartments are popular in urban area**s.**

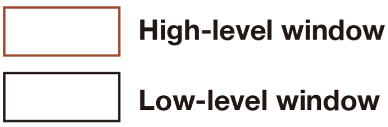


3.1.2 Opening design of the unit

Figure 3.1.7 Wind-Driven Ventilation Analysis in summer

Source: Created by author, 2024





Windows positioned **at different heights** contribute to natural cooling by promoting airflow and dissipating heat, thereby reducing the need for air conditioning. **Low-level windows bring in cooler outdoor air**, helping to lower indoor temperatures, while **high-level windows allow hot air to escape**, enhancing ventilation and supporting air circulation through the stack effect.

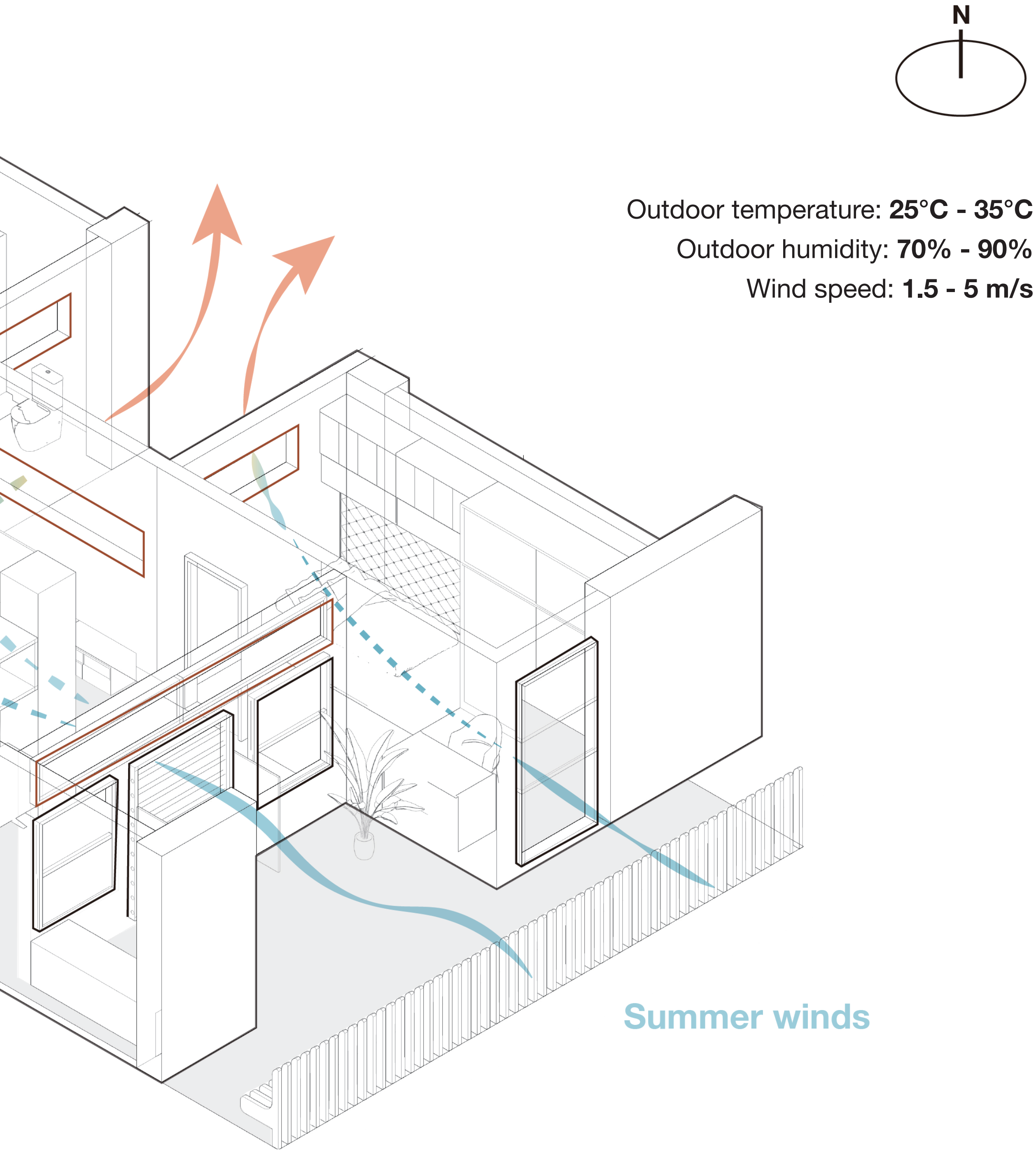
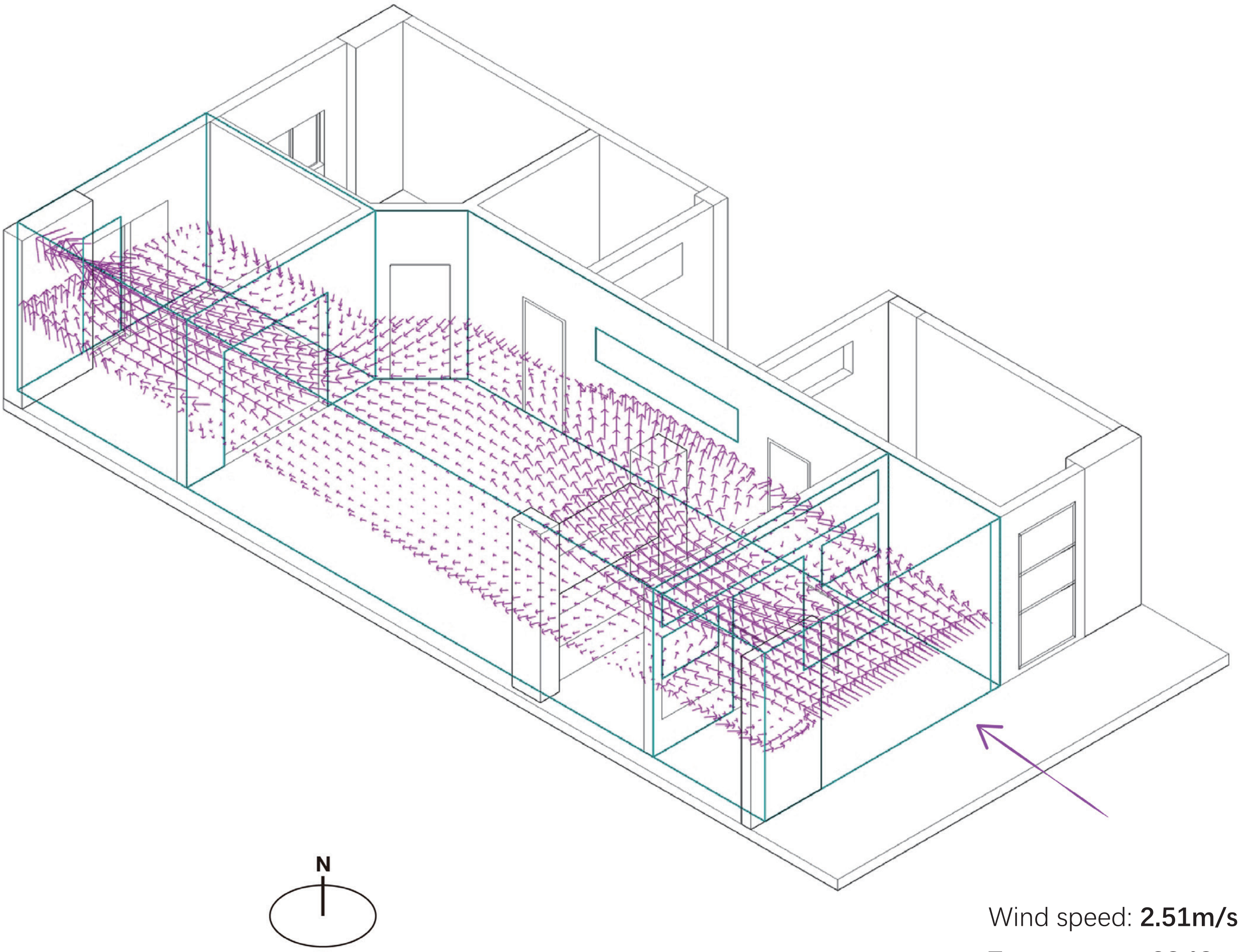

N
Outdoor temperature: **25°C - 35°C**
Outdoor humidity: **70% - 90%**
Wind speed: **1.5 - 5 m/s**
Summer winds

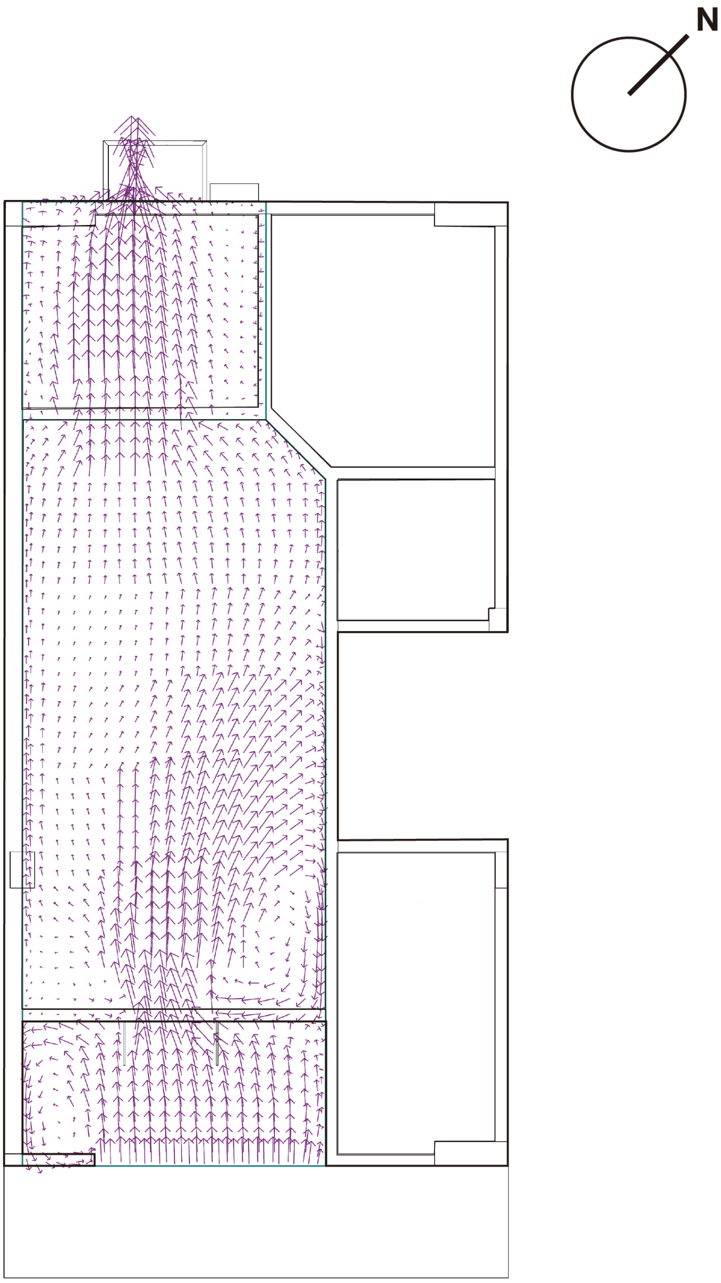
Figure 3.1.8 Airflow simulation of the unit in summer, with all windows open during the daytime
Source: Created by author, 2024
Software: ladybug, butterfly

All low-level and high-level windows are open during the daytime



Wind speed: **2.51m/s**
Temperature: **28 ℃**

Openable Windows



Data used in airflow model simulation：

Summer wind direction: southeast

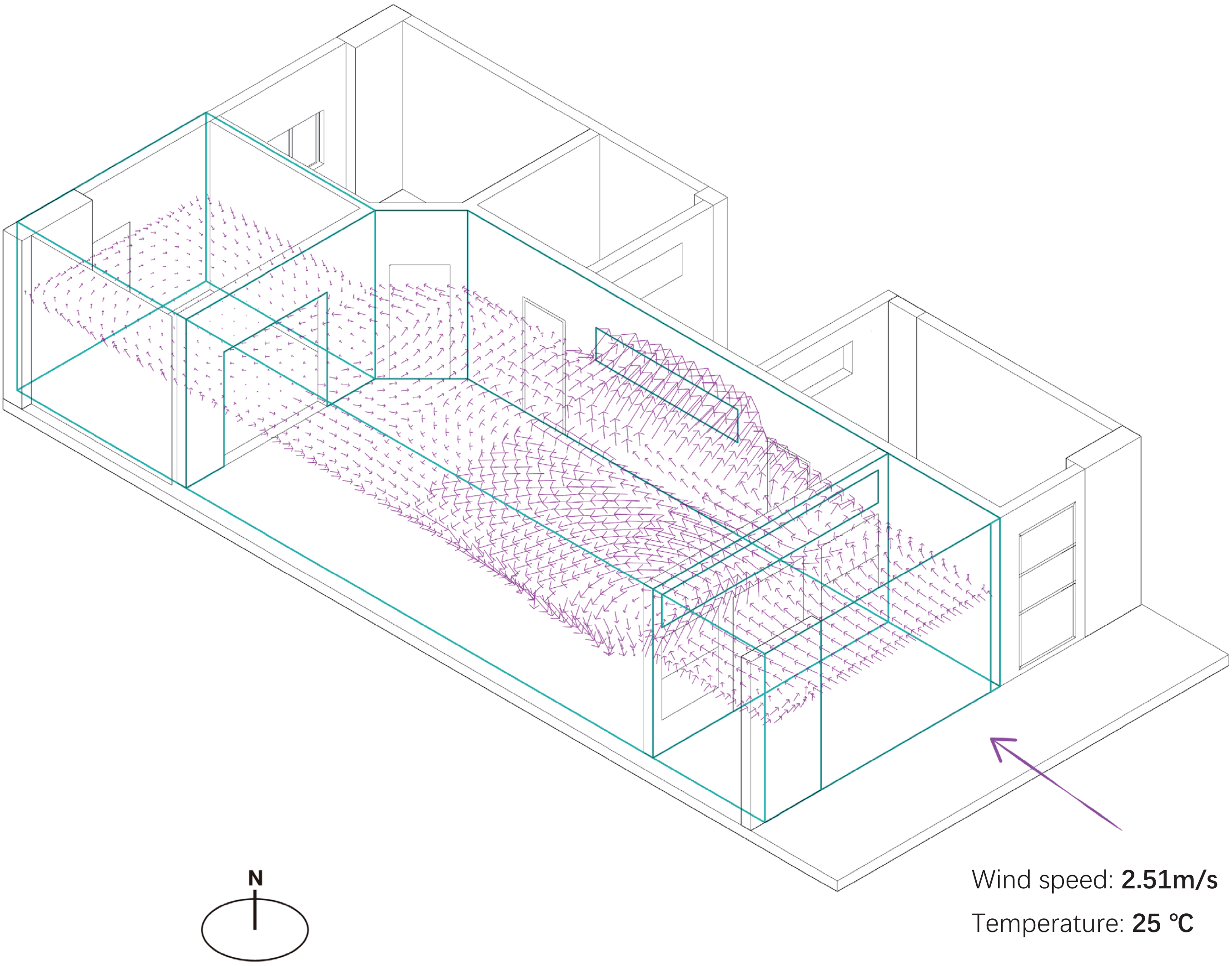
Wind speed: 2.51m/s (average of July data)

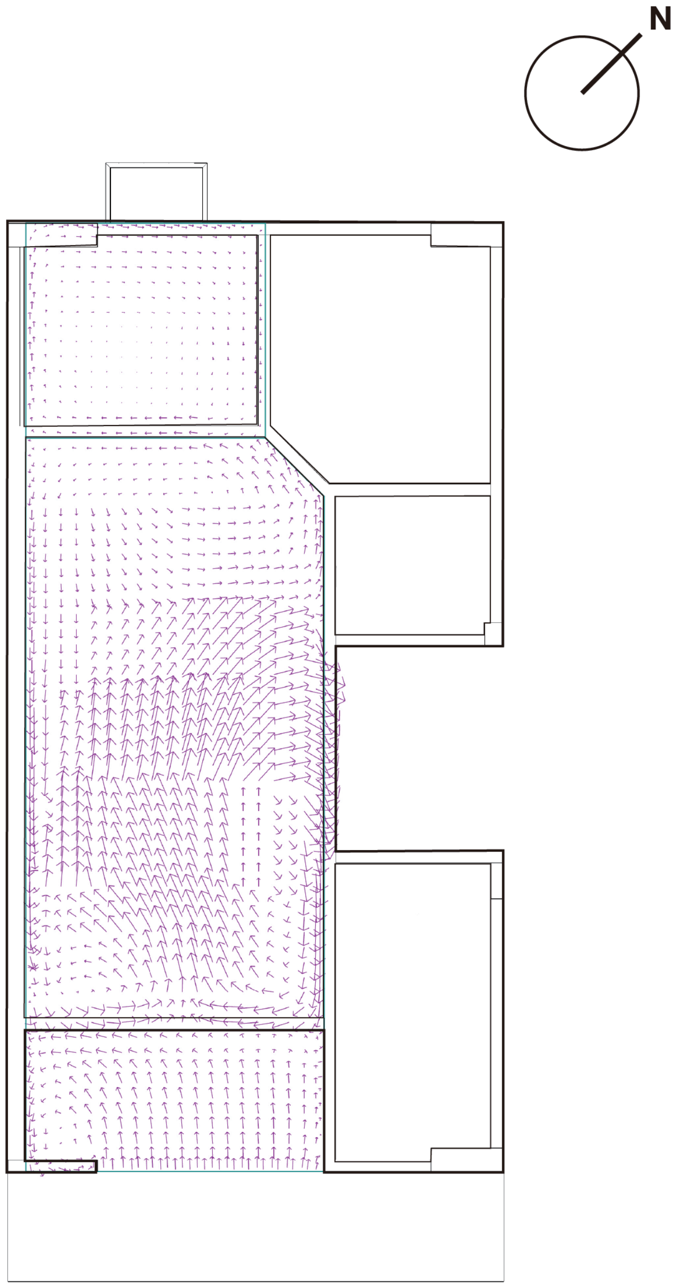
Temperature: 28 ℃ (average of July data)

Testing height level: **22.8m**

Figure 3.1.9 The unit's airflow simulation in the summer, with just high-level windows open at night
Source: Created by author, 2024
Software: ladybug, butterfly

Just high-level windows are open at night





Data used in airflow model simulation：

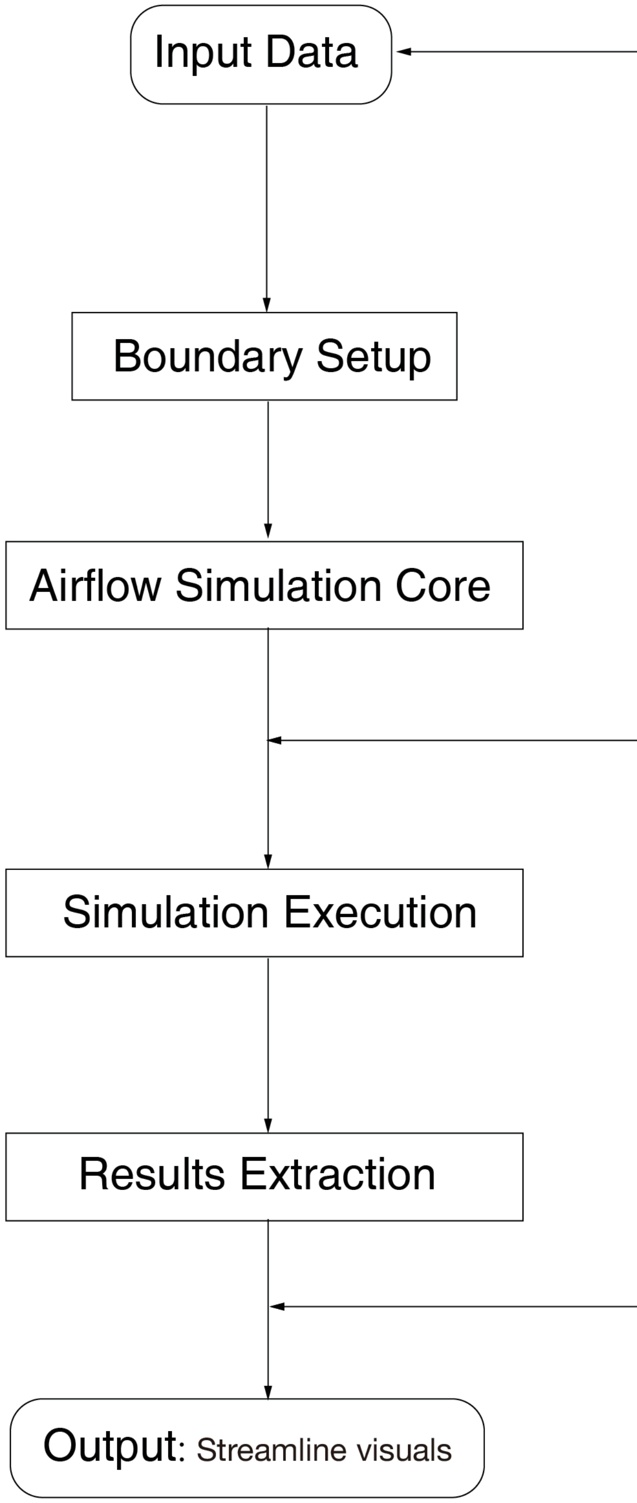
Summer wind direction: southeast

Wind speed: 2.51m/s (average of July data)

Temperature: 25 ℃ (average of July data)

Testing height level: **23.8m**

Figure 3.1.10 Workflow diagram of unit's airflow simulation based on butterfly software
Source: Created by author, 2024



Temperature conditions: 28℃

Wall Boundary

Wind Speed and Direction

Streamlines:
Toggles the activation of airflow streamlines for visualization.

Solver Parameters: Mesh refinement.

Environment Setup

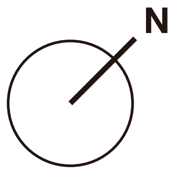
Mesh Results: Outputs data on airflow patterns and mesh quality.

Visualization: Generates a visual representation of airflow patterns using streamlines.

Evaluation: Heat exchange and Airflow velocity distribution.

3.1.3 FURNITURE DESIGN OF THE UNIT

Figure 3.1.11 Pespective plan of the unit
Source: Created by author, 2024



Arrange furniture strategically by taking into account airflow simulations to ensure that wind ducts remain unblocked. **When selecting furniture, avoid from utilizing floor-to-ceiling cupboards** to reduce interference with air circulation. Select designs that facilitate unobstructed airflow, so enhancing ventilation and preserving a comfortable indoor atmosphere.

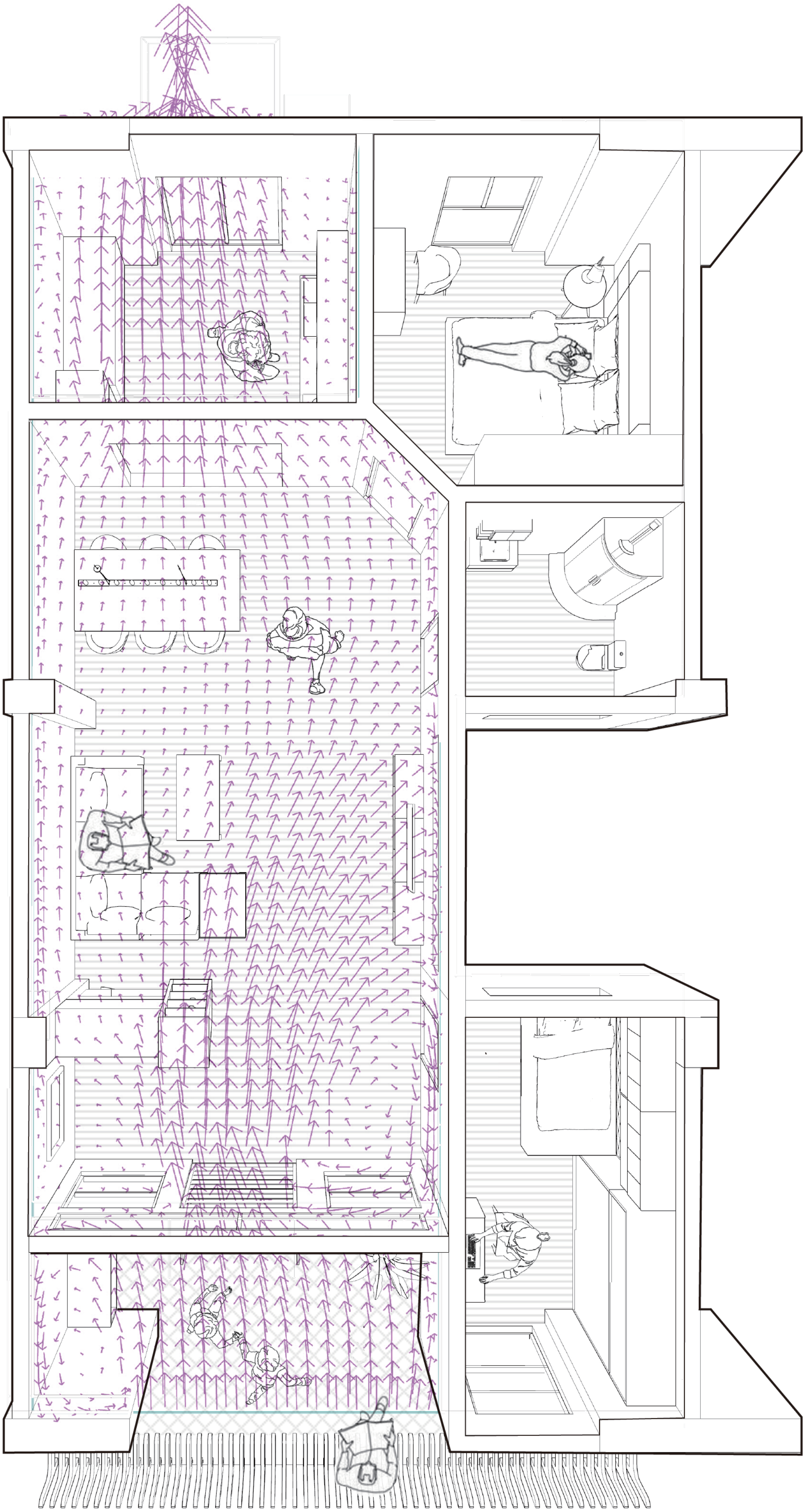
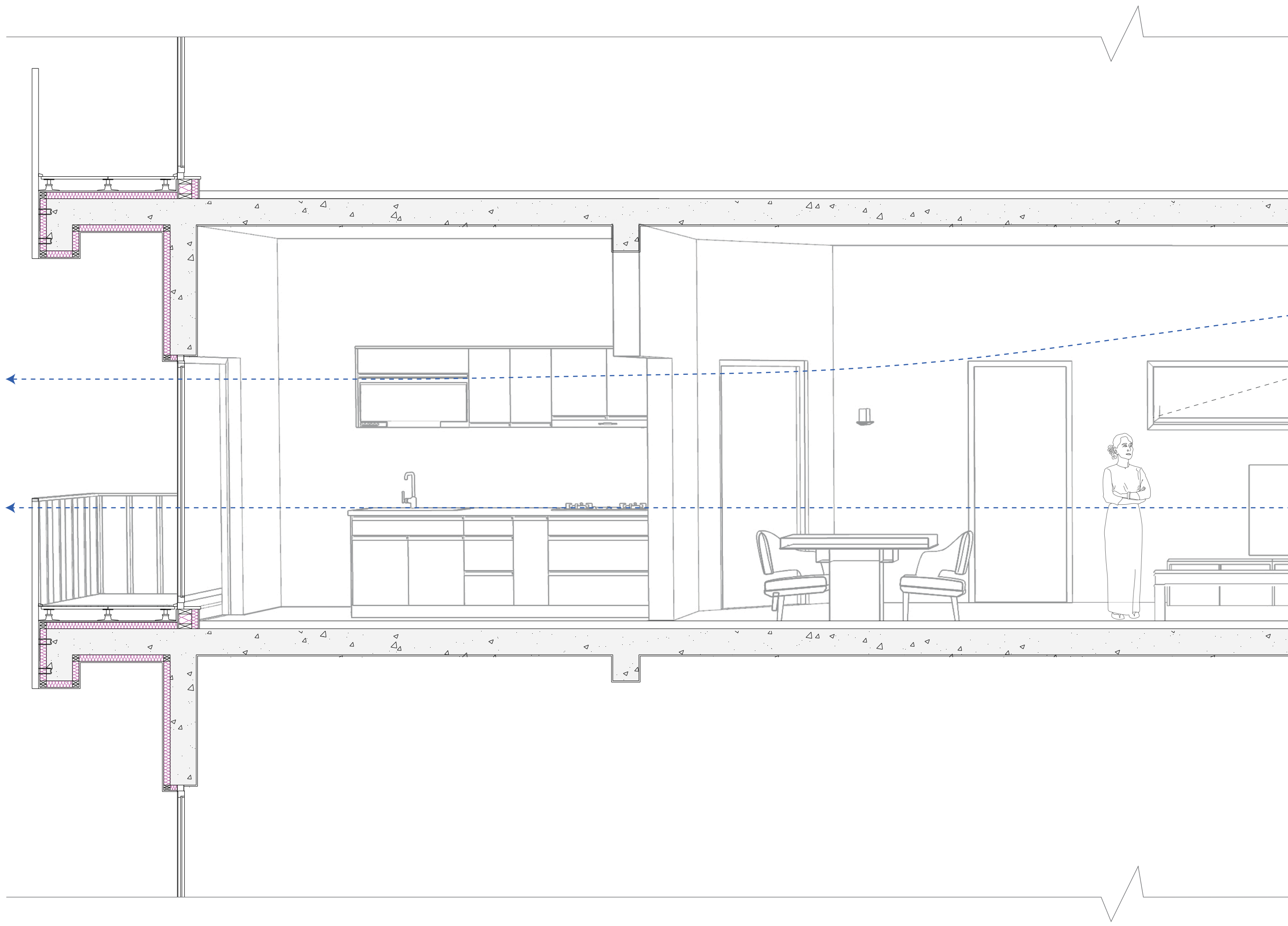


Figure 3.1.12 Detail Section Drawing of the Unit

Source: Created by author, 2024



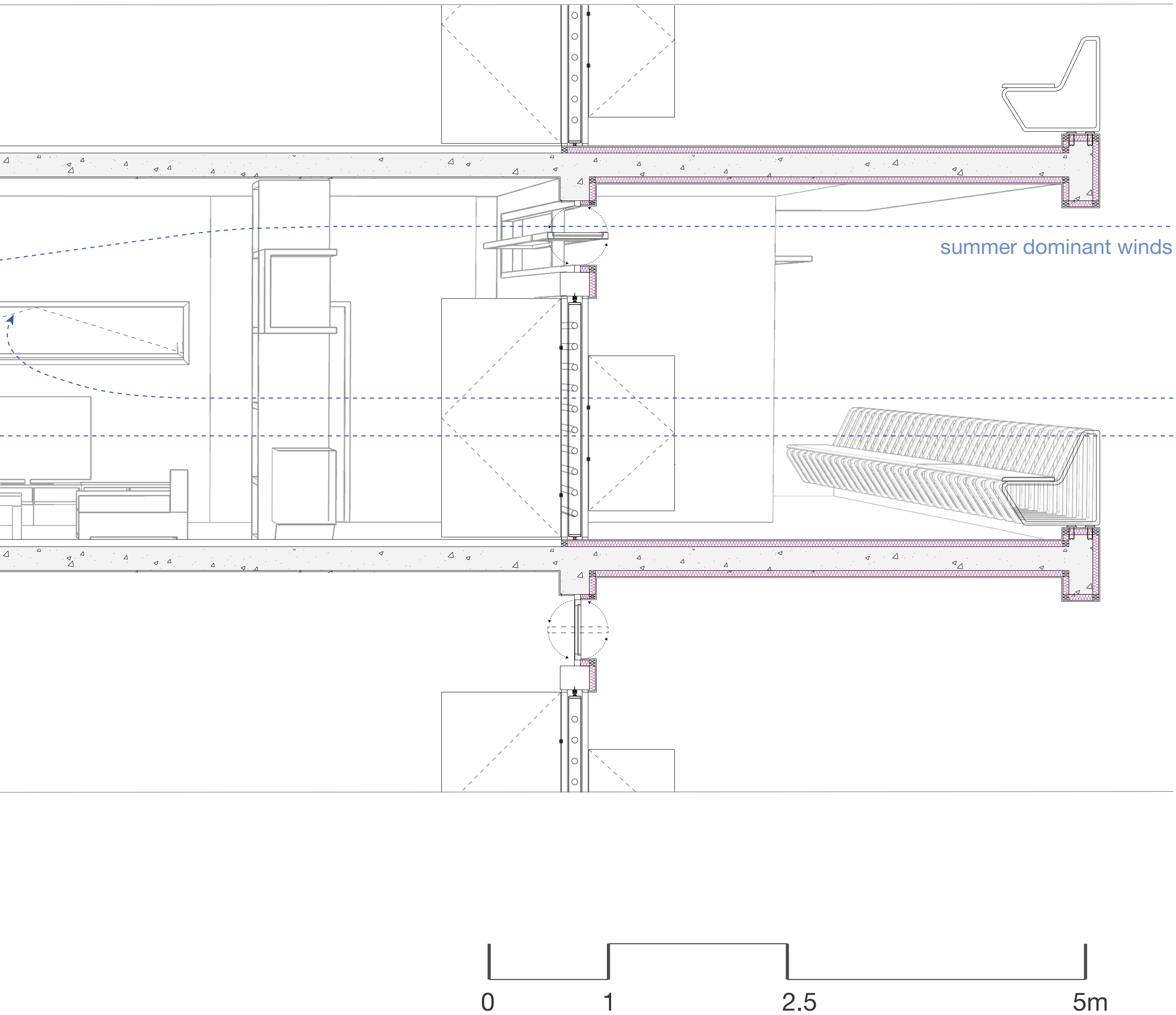
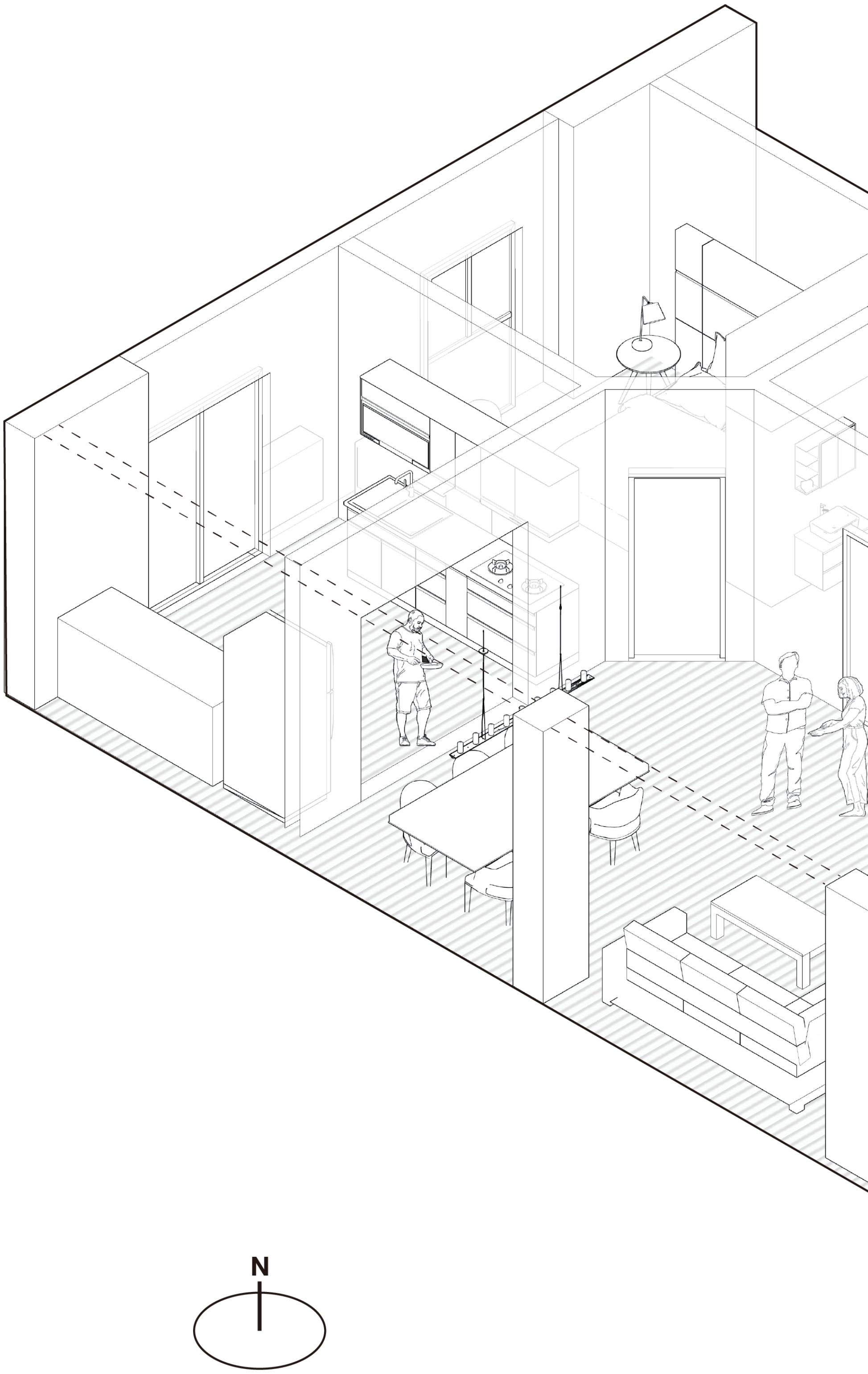

summer dominant winds
0
1
2.5
5m

Figure 3.1.13 Isometric view of the unit

Source: Created by author, 2024



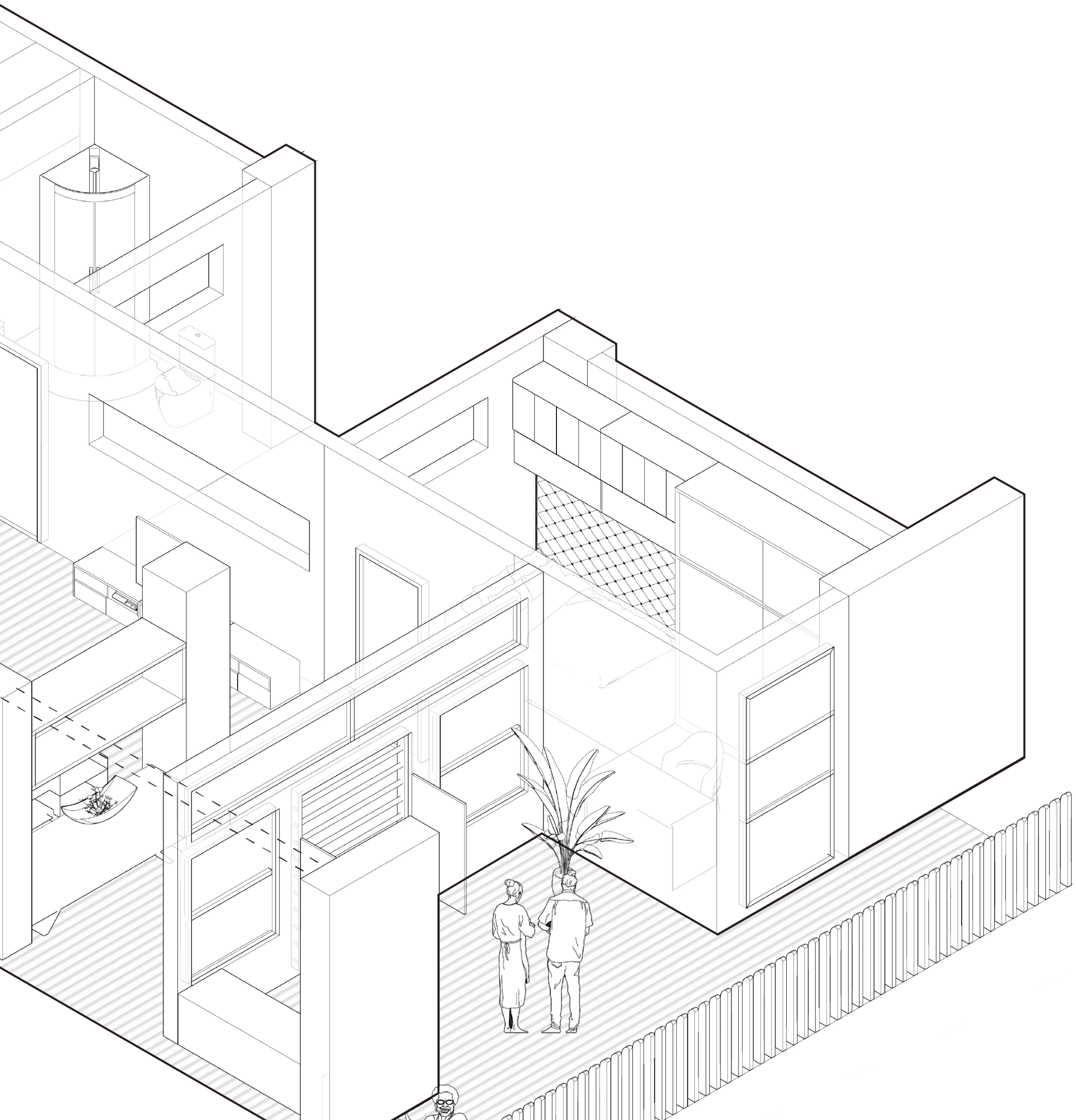
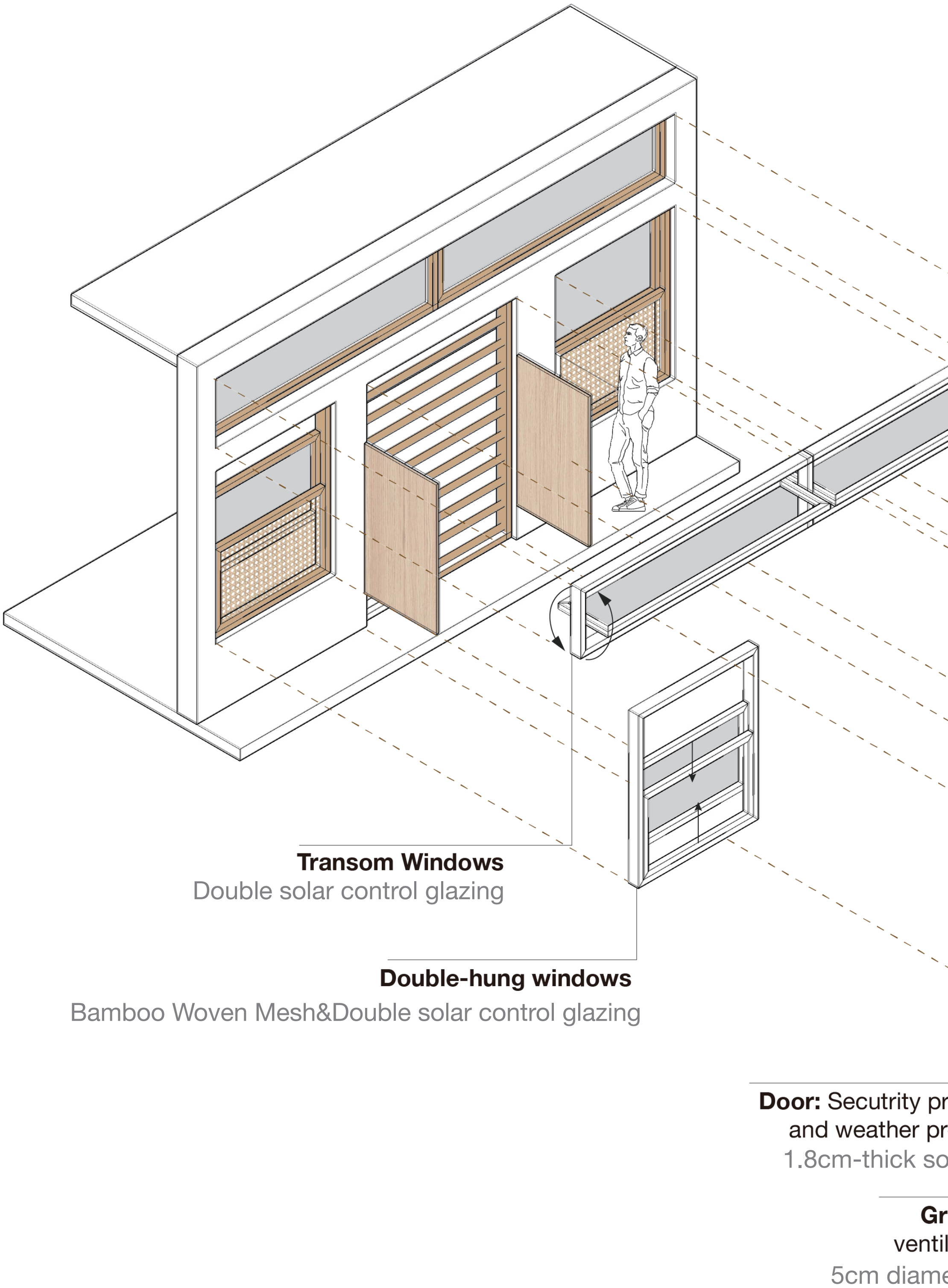
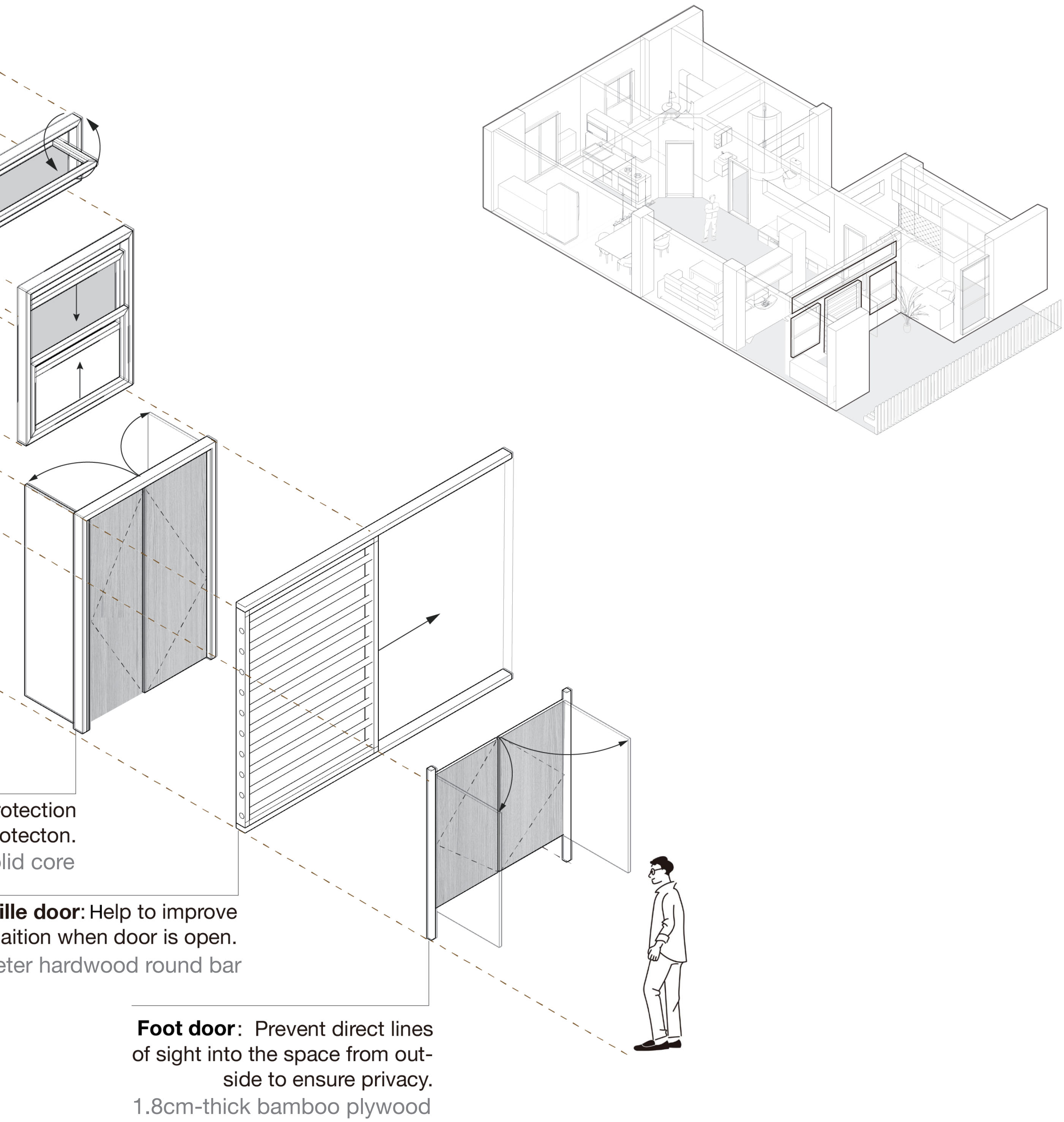


Figure 3.1.14 windows and doors design of the unit

Source: Created by author, 2024




otection
otecton.
lid core
ille door: Help to improve
aition when door is open.
eter hardwood round bar
Foot door: Prevent direct lines of sight into the space from outside to ensure privacy.
1.8cm-thick bamboo plywood

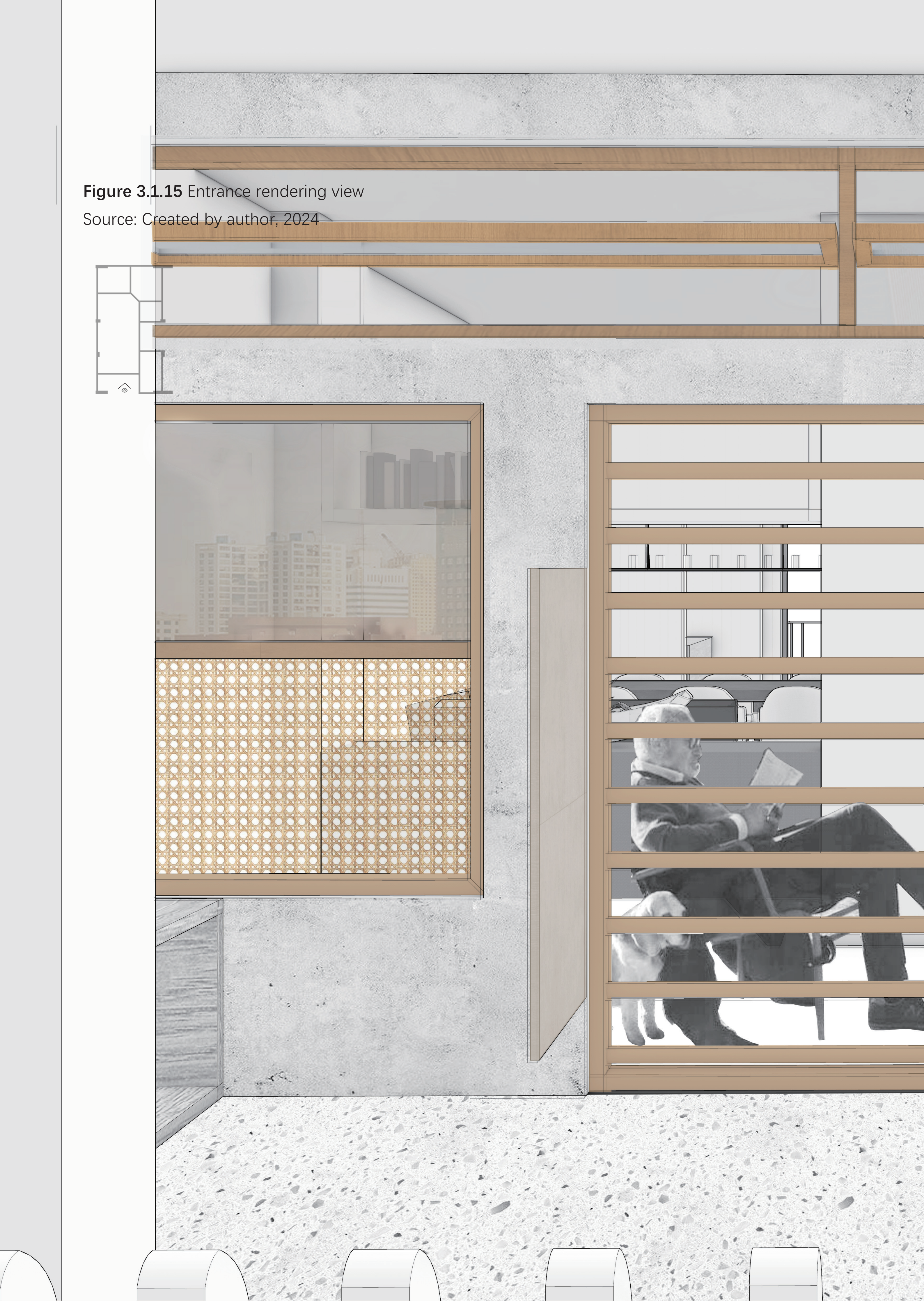


Figure 3.1.15 Entrance rendering view

Source: Created by author, 2024

Figure 3.1.16 Entrance rendering view

Source: Created by author, 2024

Figure 3.1.17 Living room rendering view

Source: Created by author, 2024

Figure 3.1.18 Bedroom rendering view

Source: Created by author, 2024

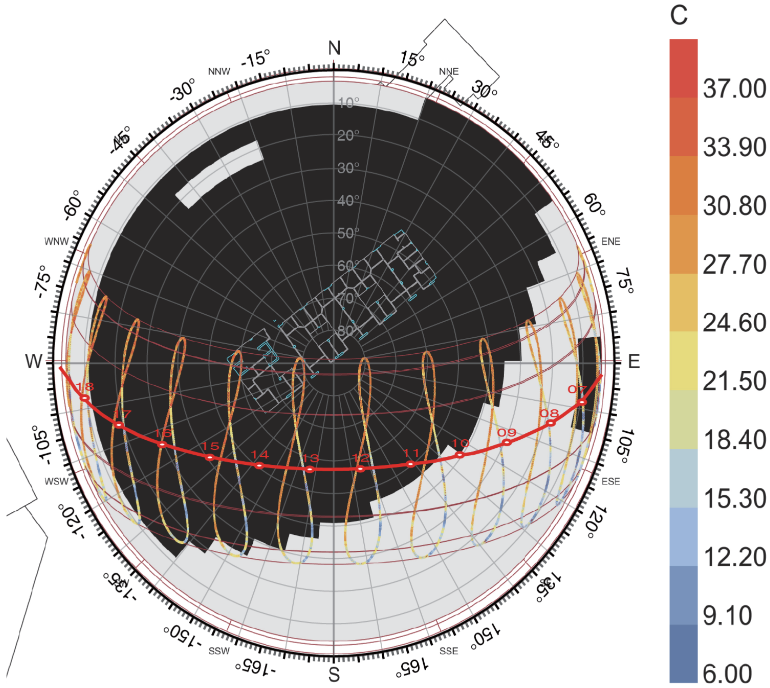
3.1.4 Shading devices design of the unit

Figure 3.1.19 Shading mask of the southeast facade windows

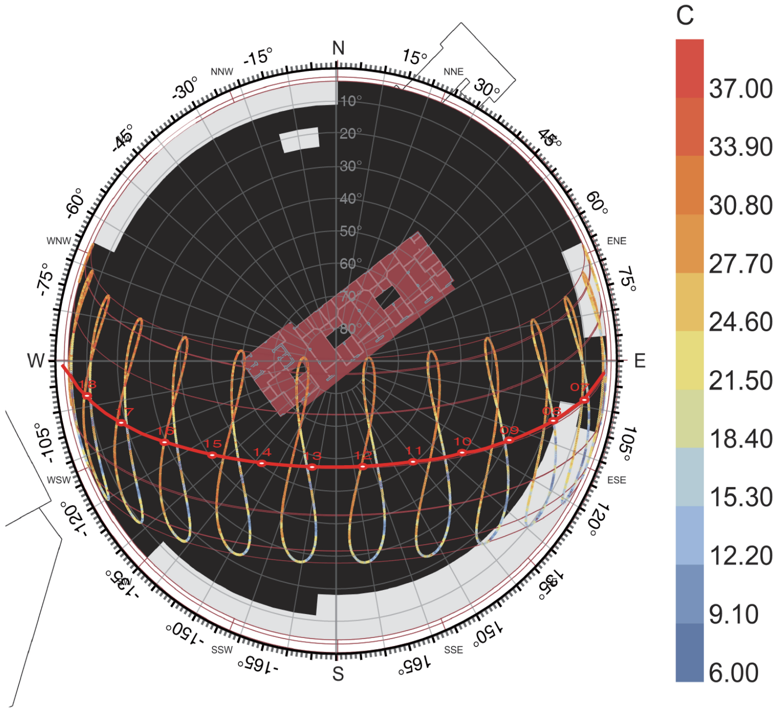
Source: Created by author, 2024

Tool: Ladybug, grashopper

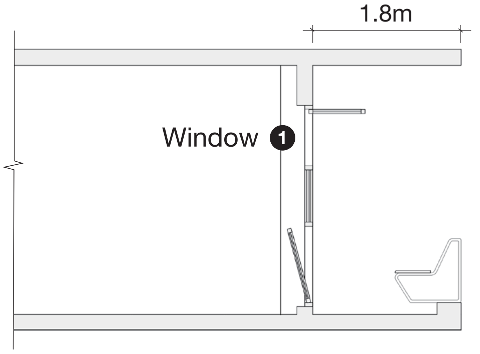
Shading mask of window 1

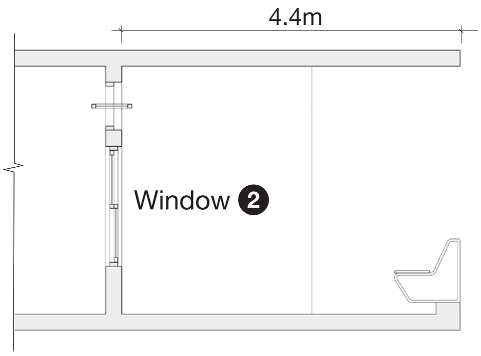


Shading mask of window 2



Dry Bulb Temperature (C)
city: GUANGZHOU
country: CHN
time-zone: 8.0
source: IWEC Data





The shading mask for **Window 1** shows that the room gets direct sunlight before 10 a.m. in the summer.The curtains are generally drawn when people are sleeping in this room because it is mostly used as a bedroom. Additionally, **since the bedroom is usually unoccupied after 8 AM, there is no need to add additional shading device to block the sunlight.**

For Window 2 which is in the living room, the shading mask shows that the window **receives direct sunlight only before 9:00 AM in winter**. At the other times, it does not receive direct sunlight, so no additional shading devices need to be designed.

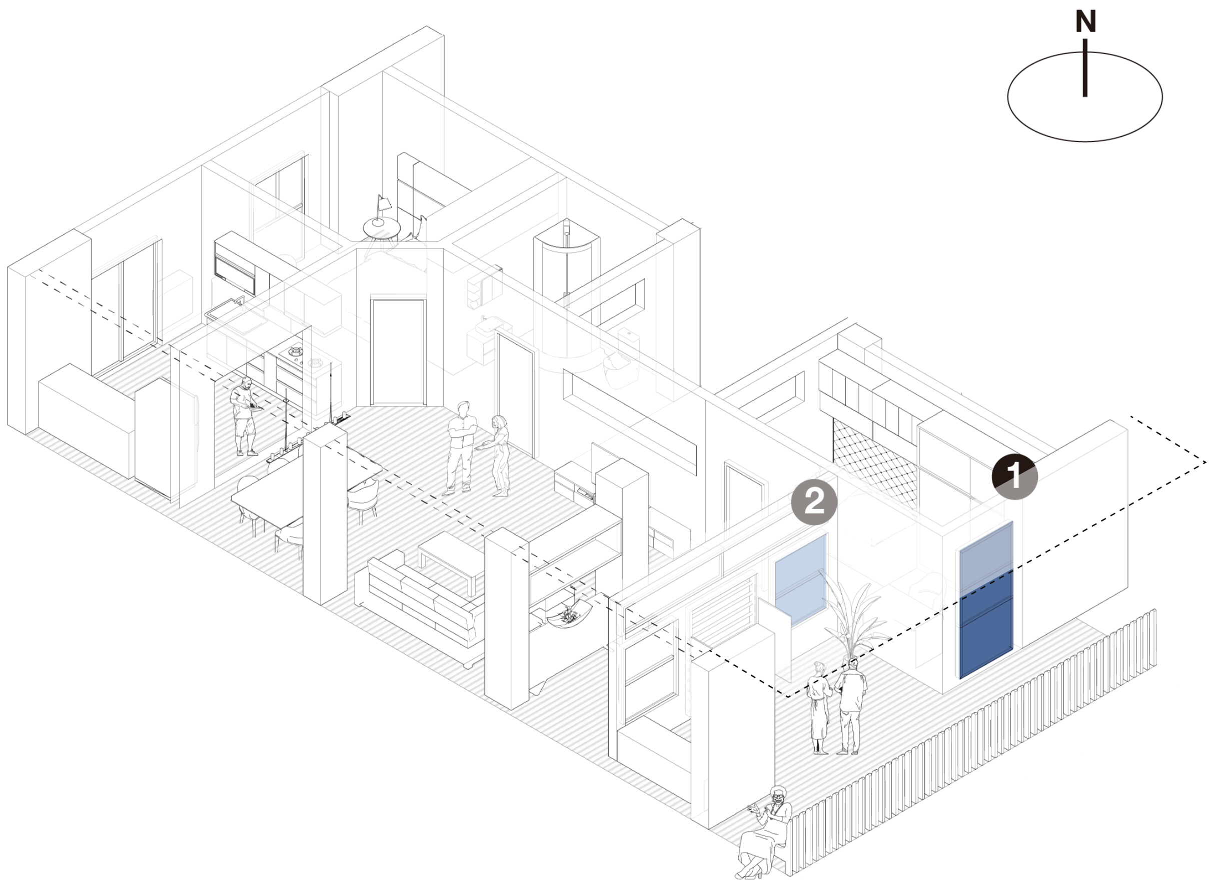
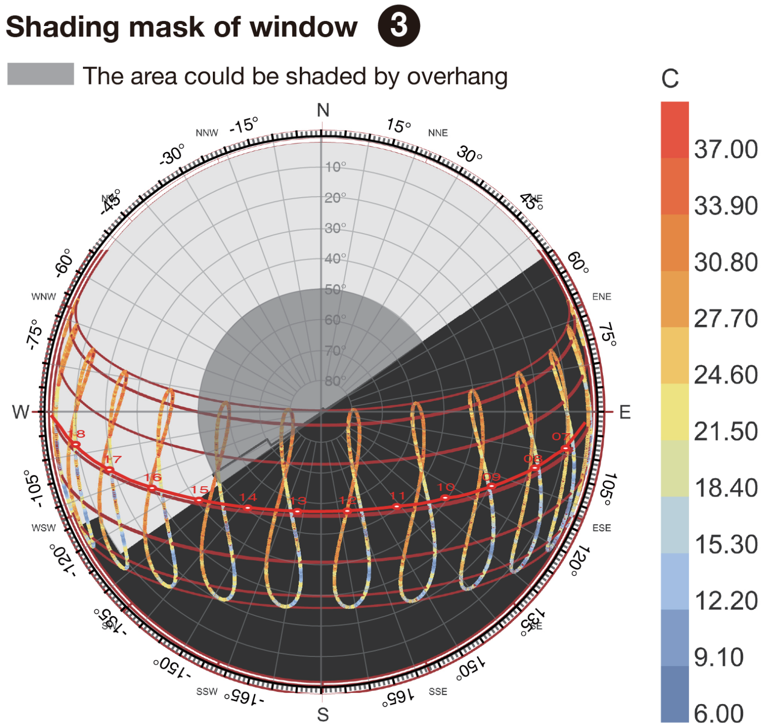


Figure 3.1.20 Shading mask of the northwest facade's windows

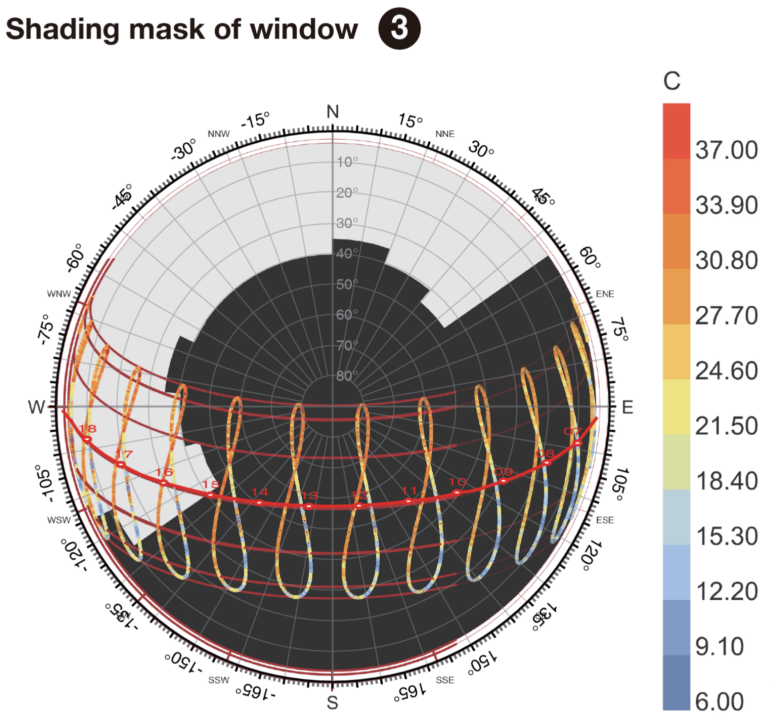
Source: Created by author, 2024

Tool: Ladybug, grashopper

Existing



Post-retrofitting

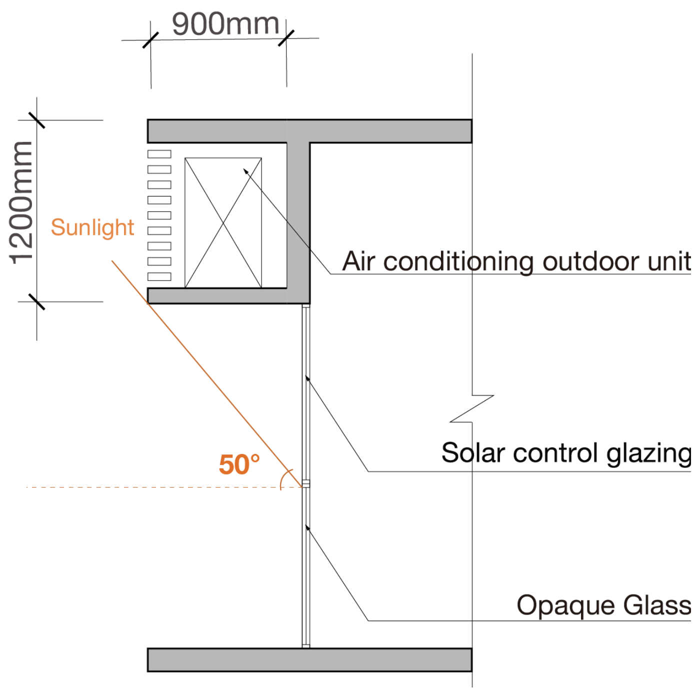


Dry Bulb Temperature (C)
city: GUANGZHOU
country: CHN
time-zone: 8.0
source: IWEC Data

For window 3, in summer, it gets direct sunshine from 1:00 PM until sunset. Although it function as a bedroom and it is unoccopied at that time, a shading devices still necessary be designed to prevent heat from being trapped between 12:00 PM and 2:00 PM , when the sun's rays hit the ground at the most direct angle, resulting in the shortest atmospheric path and the highest concentration of heat.

The overhanging is designed together with the place where the air conditioner outdoor unit is placed. **This method improves thermal comfort by shading direct sunlight during peak hours (solar angle 50° -90 °) to preserving energy efficiency and reducing extra construction required.**

Shading Device design

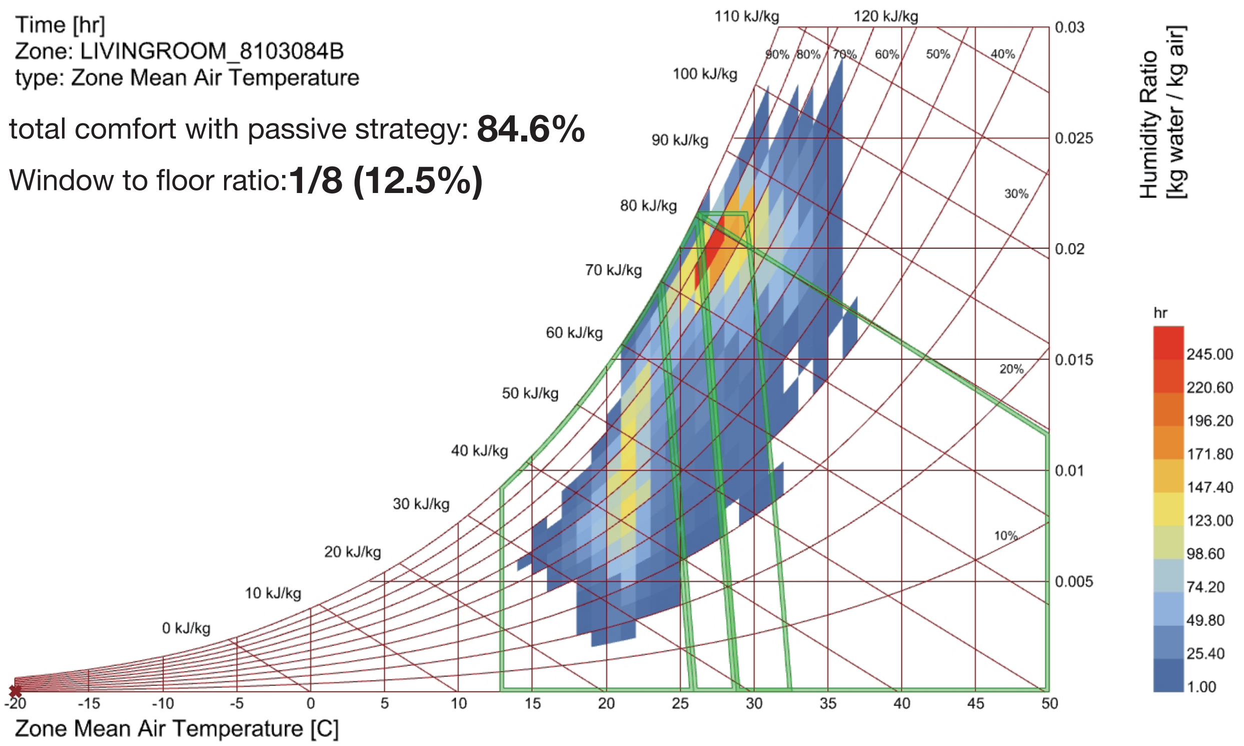


3.1.5 Indoor thermal comfort analysis of the unit

Figure 3.1.21 Psychrometric chart and indoor thermal comfort of the living room

Source: Created by author, 2024

Tool: Honeybee, grashopper



Without relying on any HVAC system, the Indoor thermal comfort of each rooms in the unit were simulated,—the following comfort levels were achieved:

• **The living room** maintained a comfortable state for **90.4%** of the occupied time when all the windows were open, but the figure dropped to **28.6%** with the windows closed.

• **The southeast-facing bedroom** for **98.3%** of the occupied time, the figure dropped to **39.3%** with the windows closed.

• **The northwest-facing bedroom** for **94.8%** of the occupied time, the figure dropped to **30.8%** with the windows closed.

The lower comfort percentage in the living room is primarily due to the higher metabolic rate associated with sitting activities (1.0 Met) compared to sleeping in the bedrooms (0.7 Met). As can be seen from the chart, while the design significantly enhances thermal comfort, **approximately 10% of the time, HVAC systems are need to mitigate humidity and temperature** to achieve the thermal comfort.

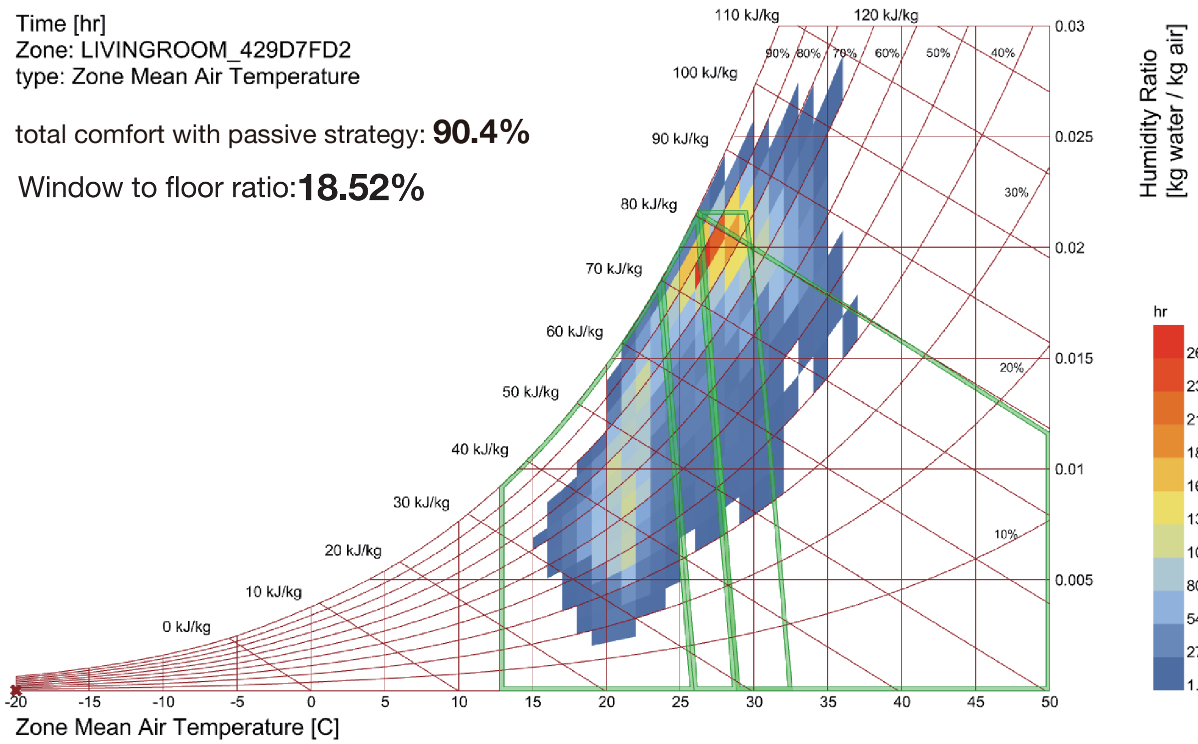
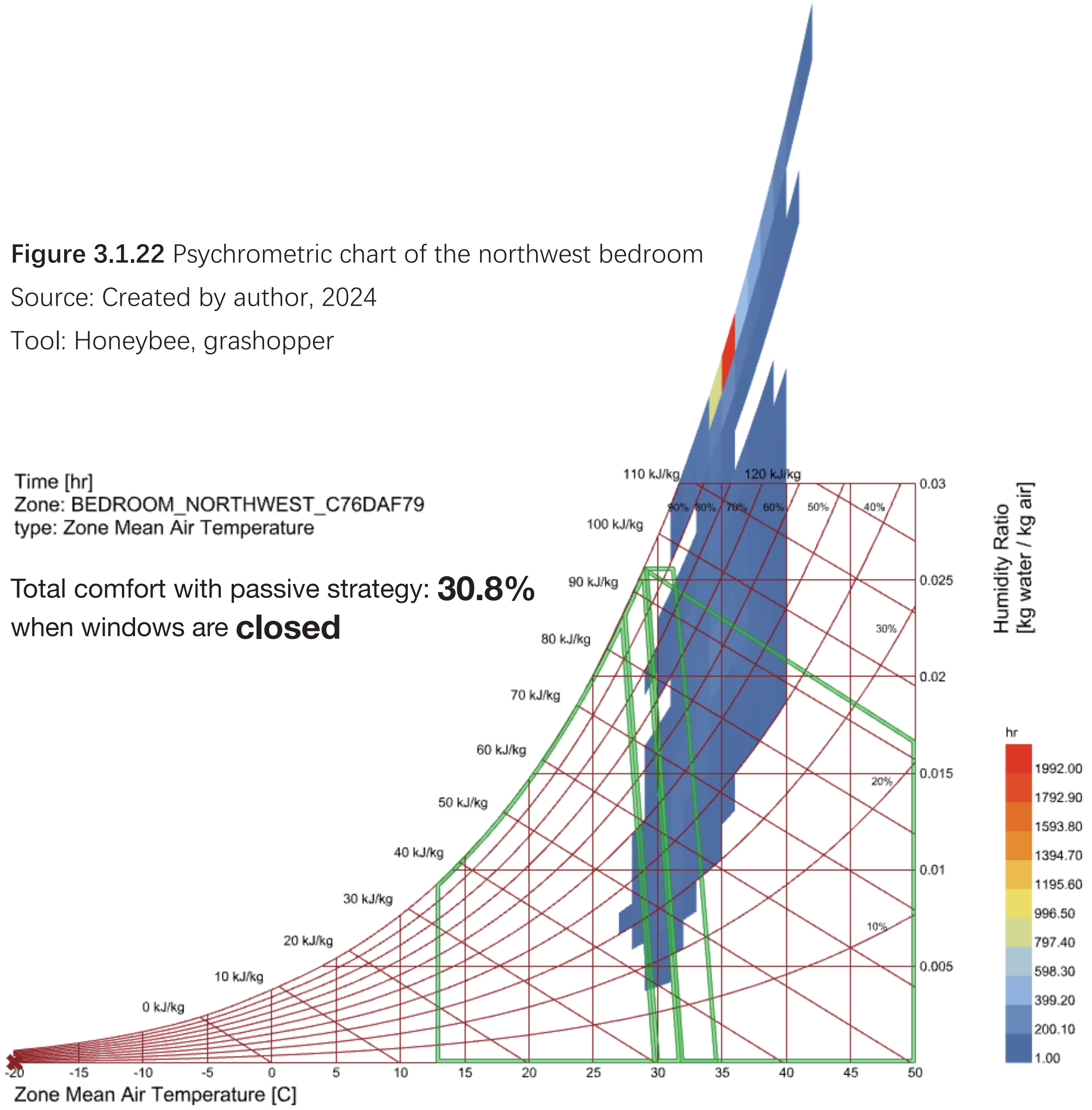


Figure 3.1.22 Psychrometric chart of the northwest bedroom
Source: Created by author, 2024
Tool: Honeybee, grashopper



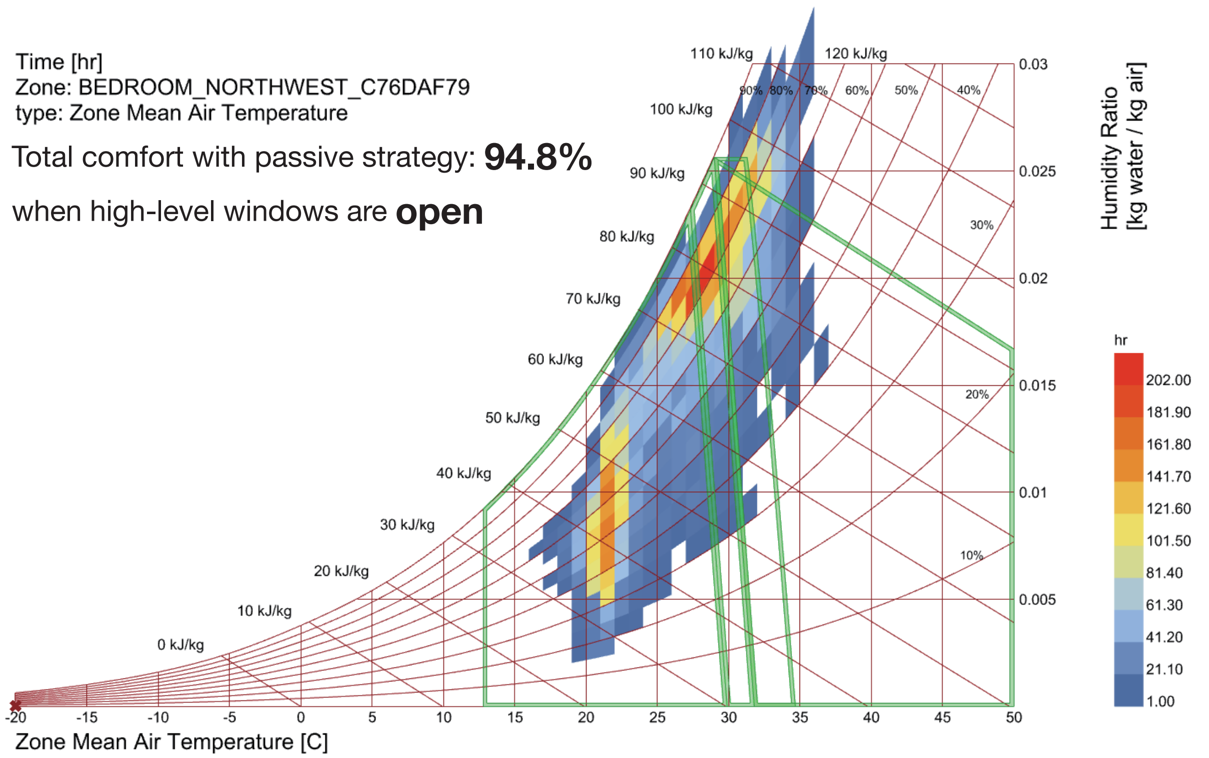
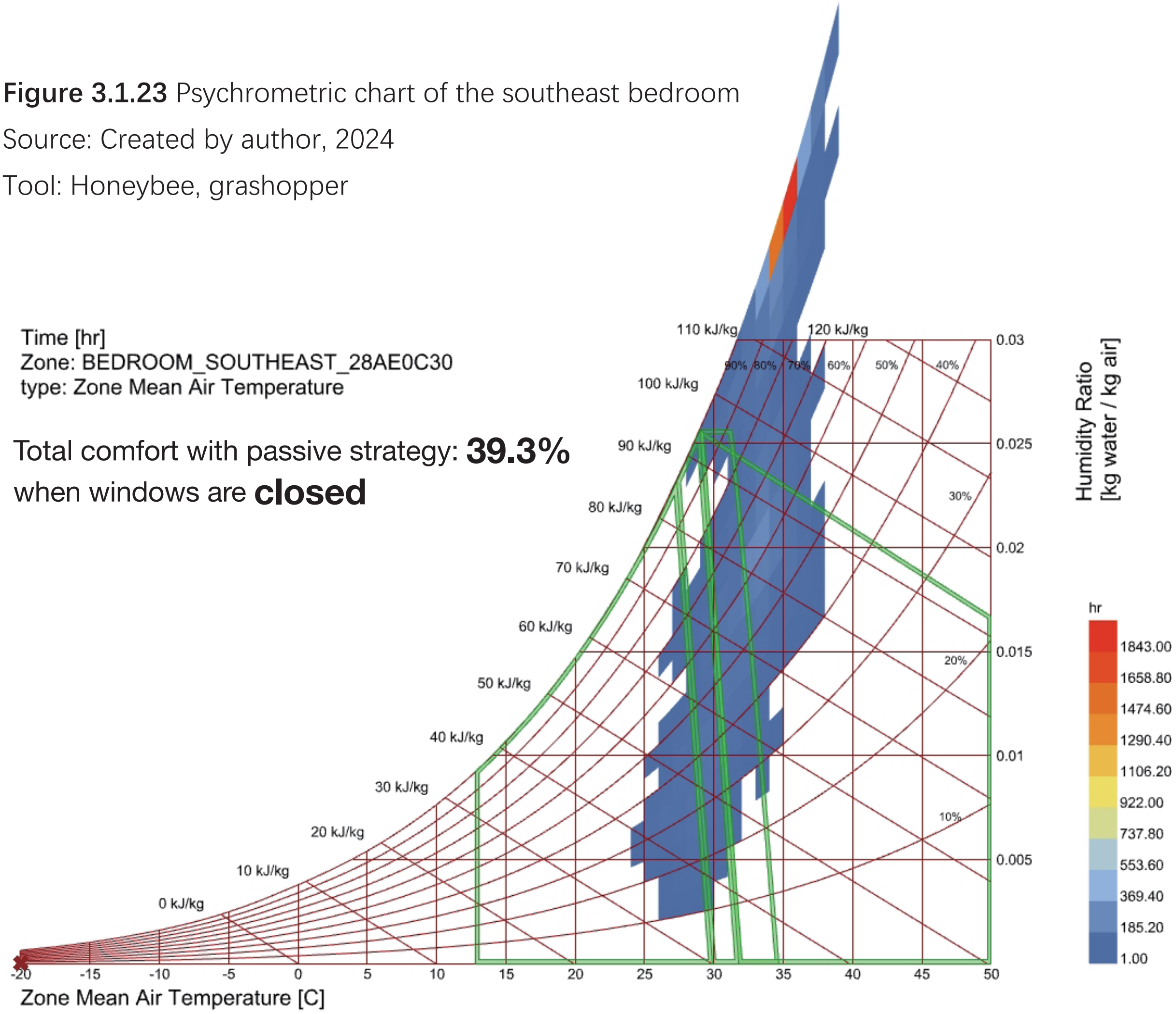


Figure 3.1.23 Psychrometric chart of the southeast bedroom

Source: Created by author, 2024

Tool: Honeybee, grashopper



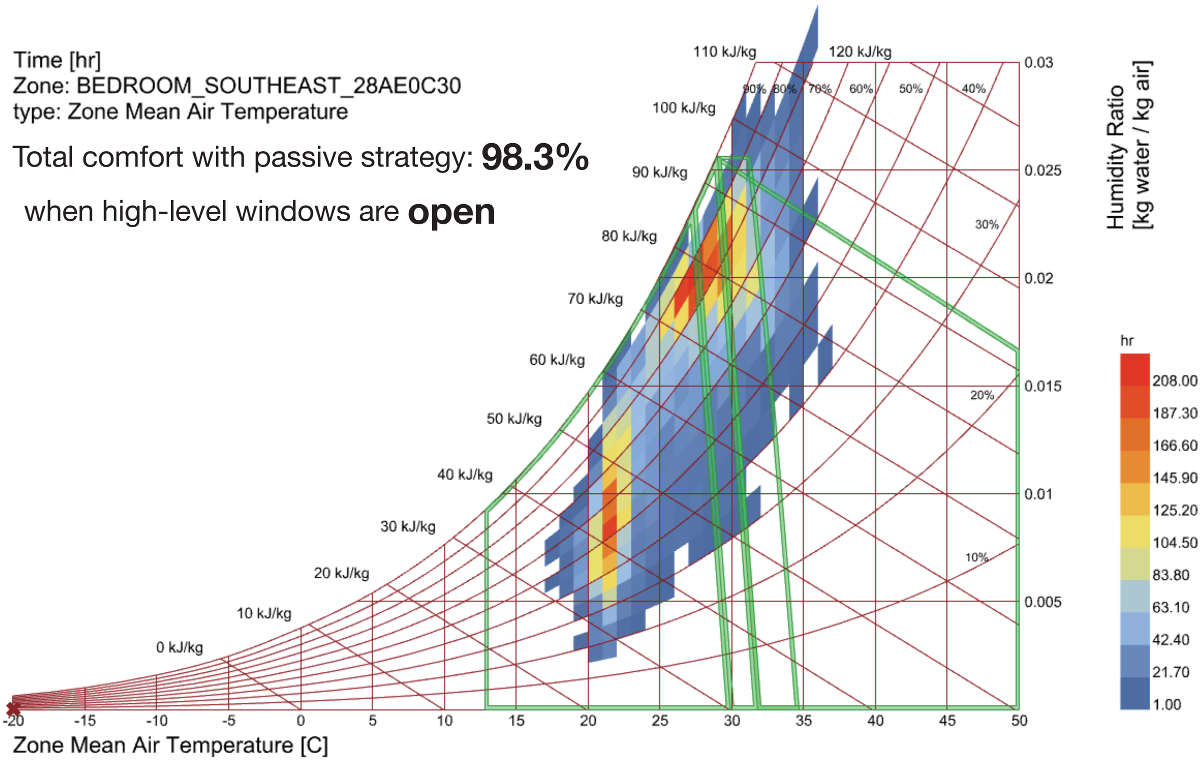
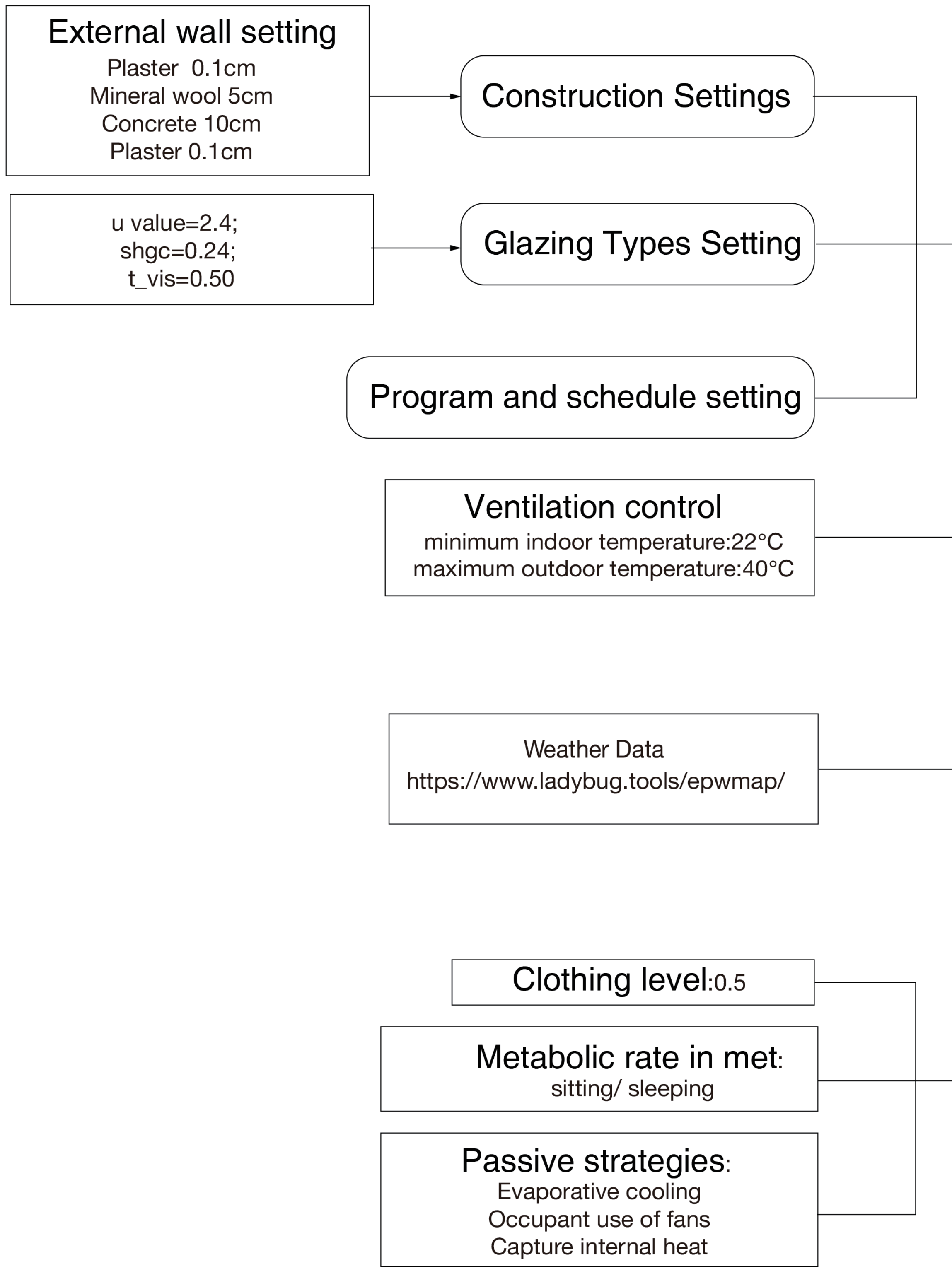
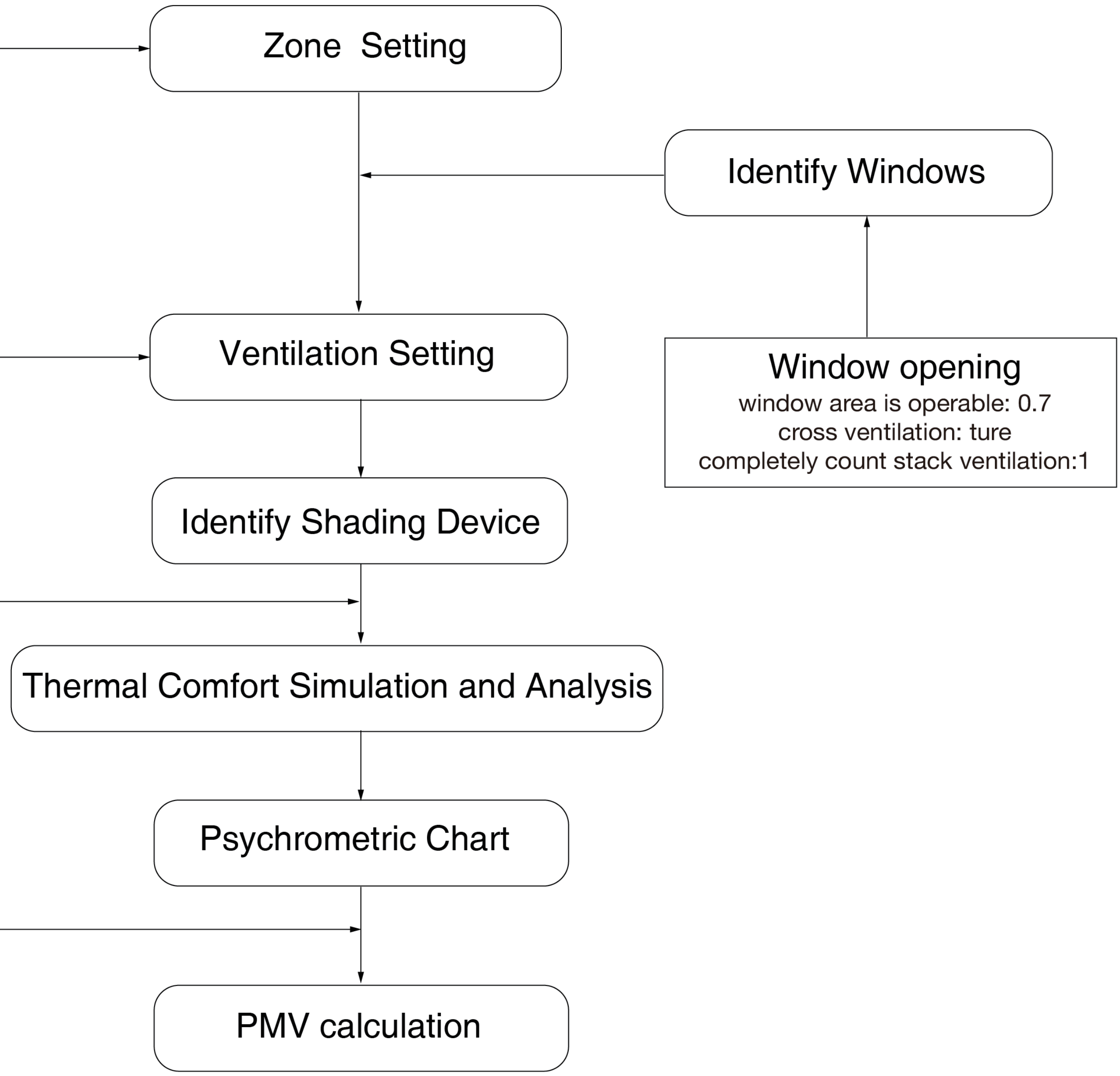


Figure 3.1.24 Workflow diagram of unit's indoor thermal comfort based on honeybee software
Source: Created by author, 2024




Zone Setting
Identify Windows
Ventilation Setting
Window opening
window area is operable: 0.7
cross ventilation: ture
completely count stack ventilation:1
Identify Shading Device
Thermal Comfort Simulation and Analysis
Psychrometric Chart
PMV calculation

3.1.6 Building envelop design of the unit

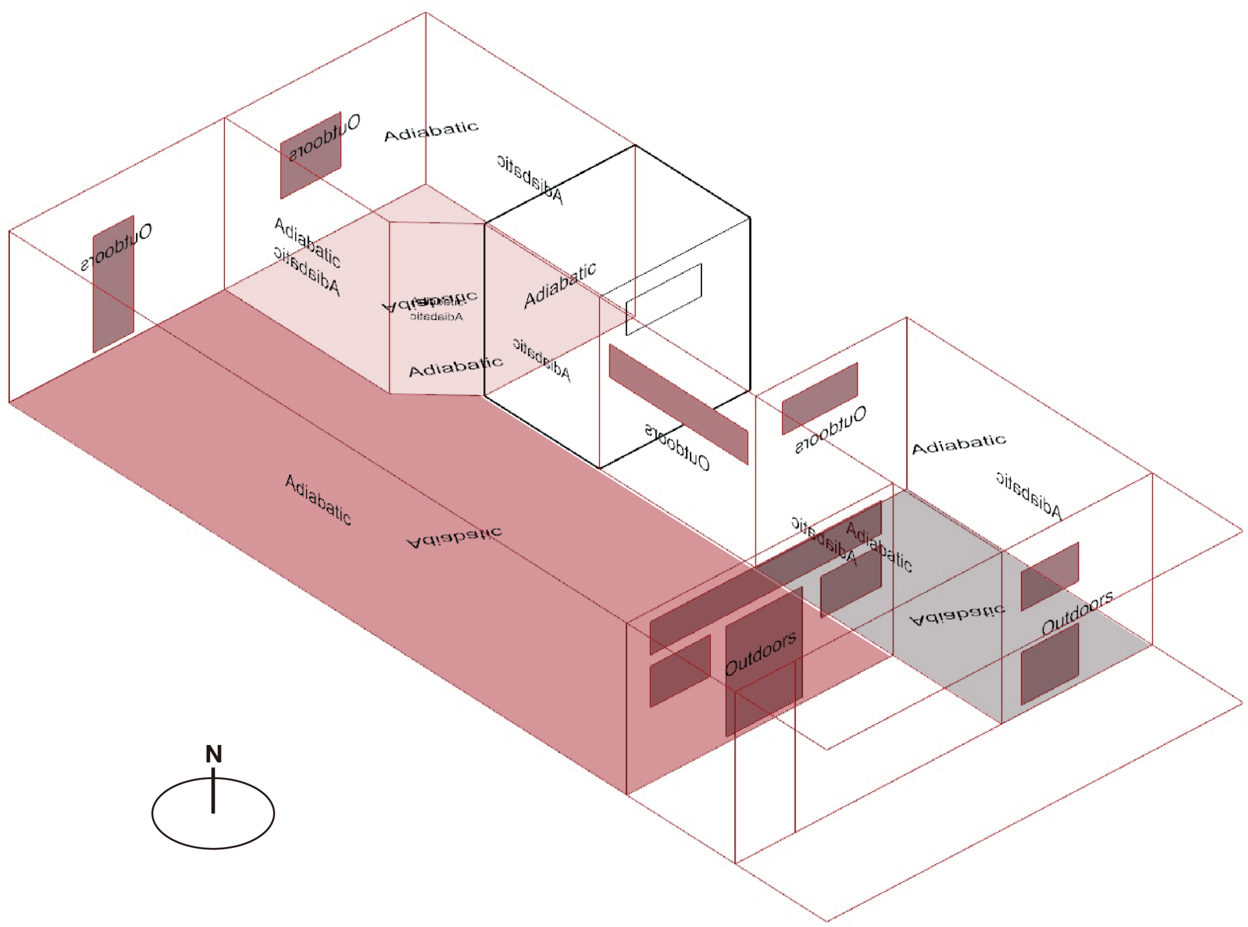
Figure 3.1.25 Energy simulation model of the unit

Source: Created by author, 2024

zone 1（16.1 ㎡）

zone 2（17.8 ㎡）

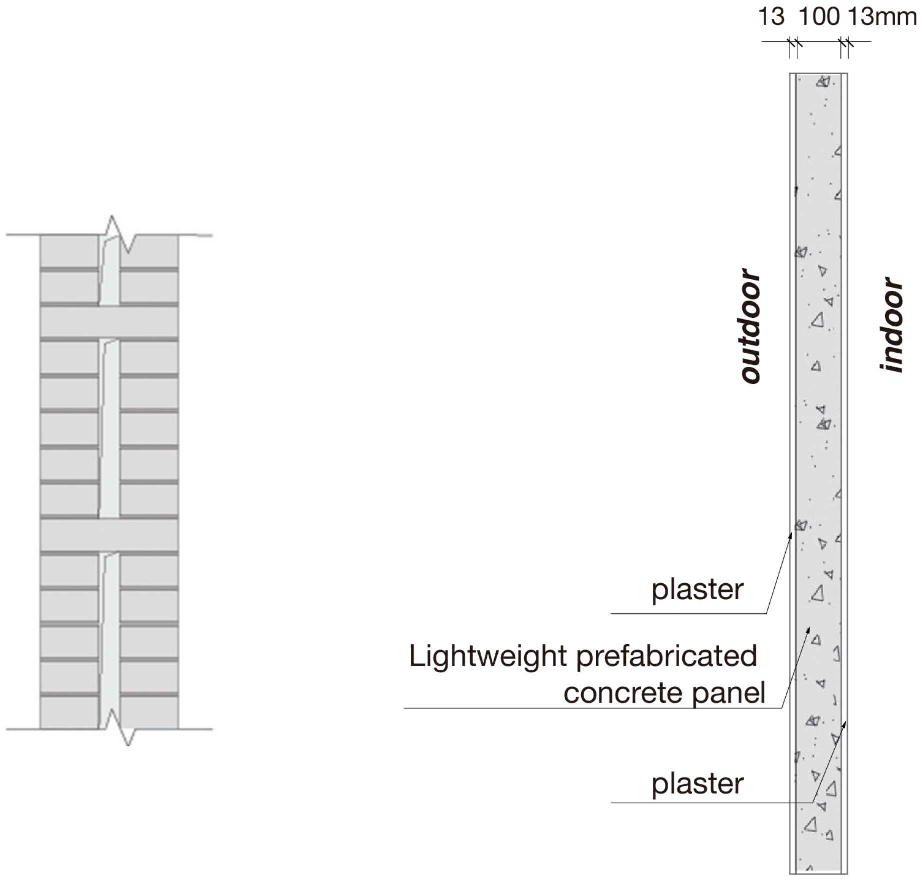
zone 3（67.5 ㎡）



Energy Simulation model

Software: ladybug, honeybee

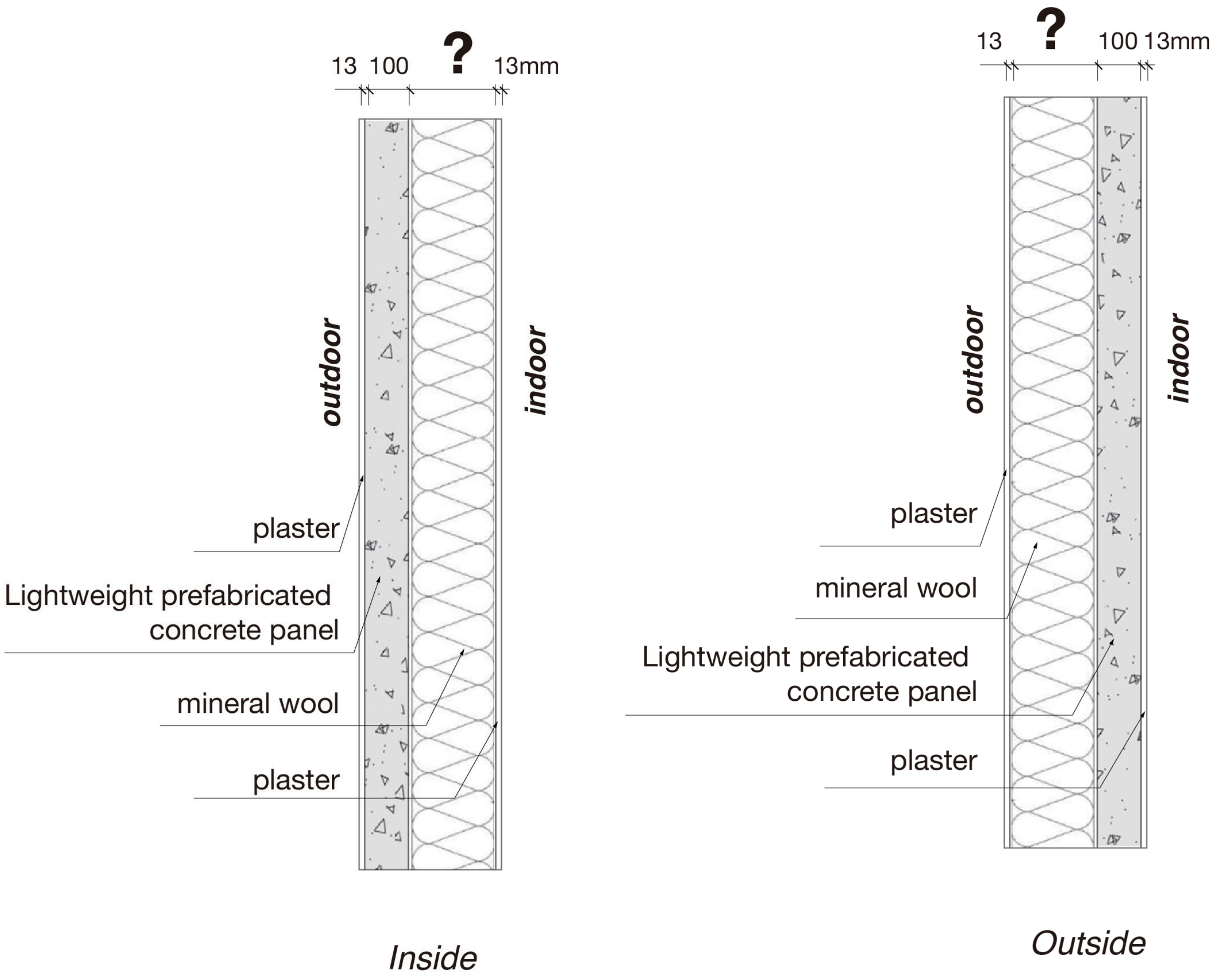
Figure 3.1.26 Cavity Walls in Lingnan Trandition dewelling and Typical Fabric Wall in High-rise buildings
Source: Repair Drawings of Historical Buildings in Guangzhou, Page 42

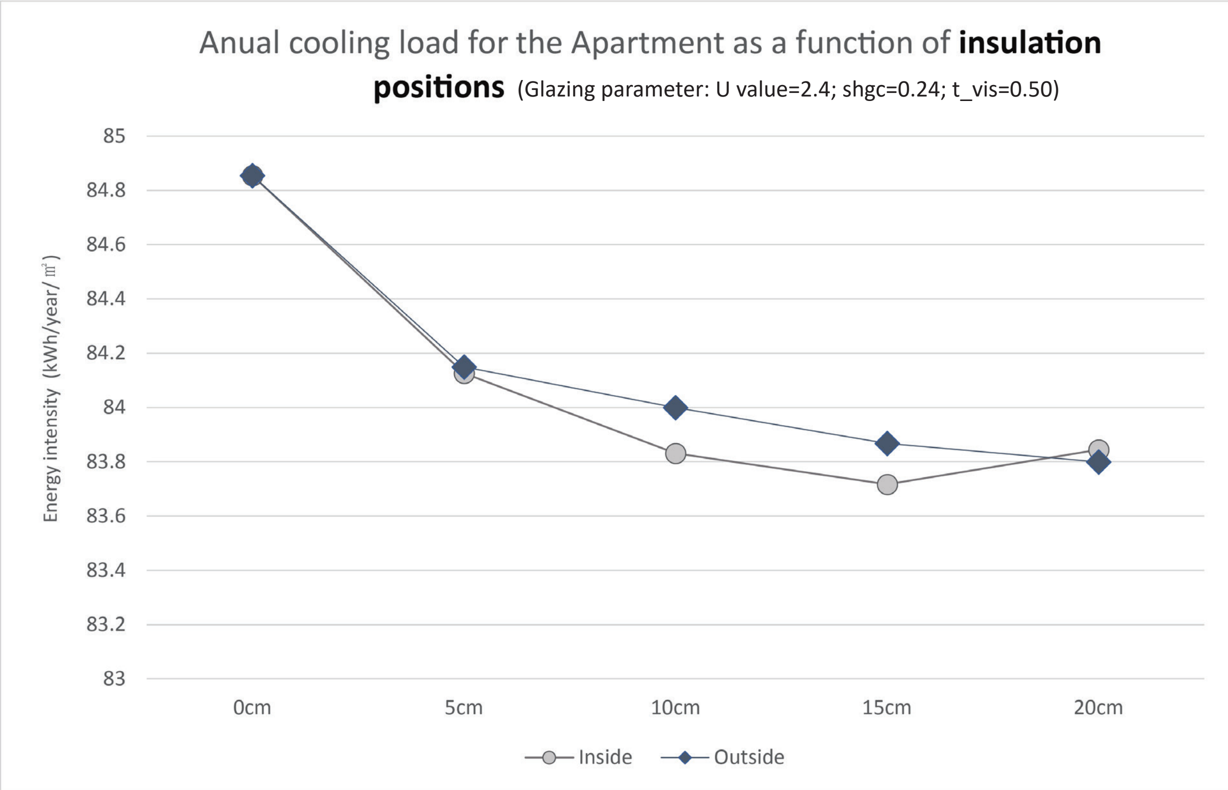


Cavity Wall Cross-section　　Prefabricated concrete wall Cross-section

In traditional Lingnan dwellings, cavity walls are often used as exterior walls to achieve the purpose of thermal insulation, but there are few cases of using insulation in the exterior wall construction of modern Lingnan buildings. This is primarily due to the local building code's lack of explicit regulations on the subject. Insulation is directly disregarded in order to reduce construction costs. However, the use of insulation is not just limited to cold regions. For hot regions like Lingnan reagion, where need to use air conditioning, adding insulation can effectively reduce the cooling load.

Figure 3.1.27 Anual cooling load for different zone as a function of insulation positions
Source: Created by author, 2024

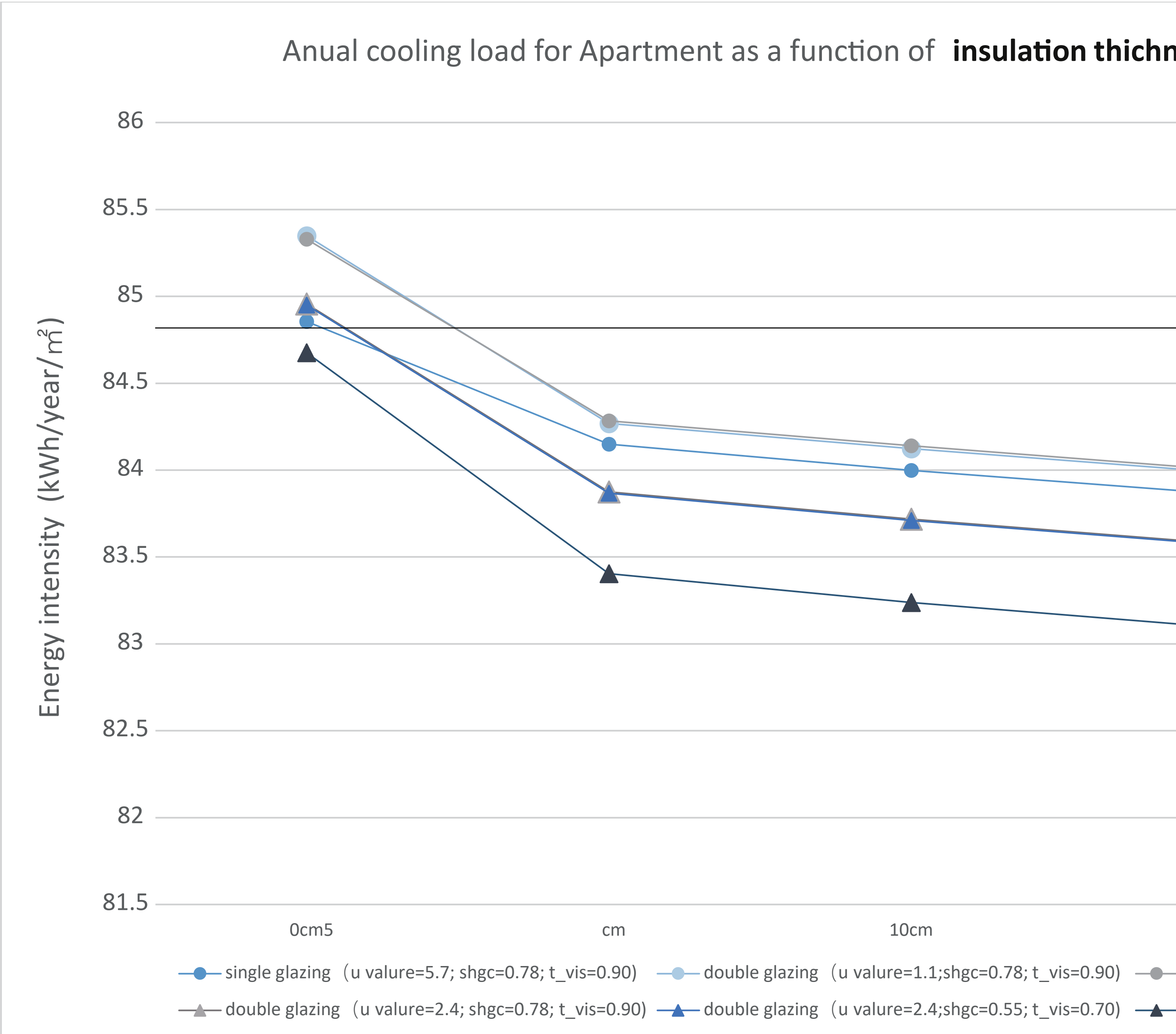


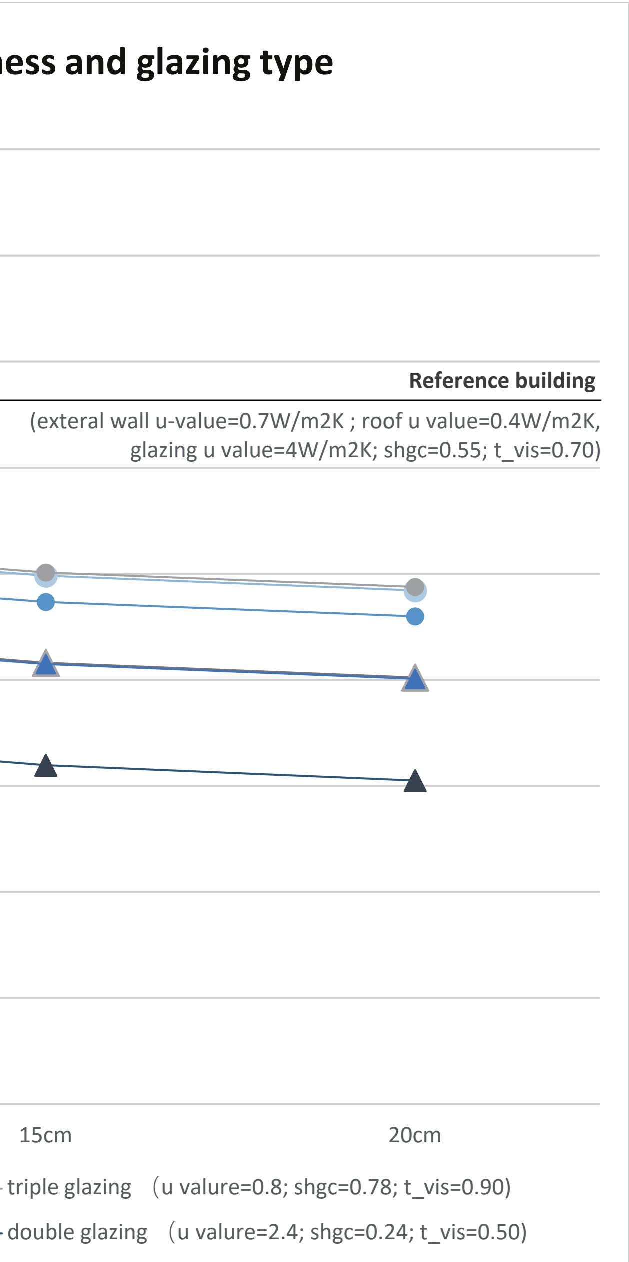


Initially, the cooling load was simulated based on the current design model for different insulation placements within the exterior wall structure.The simulation data indicates that when the thickness of insulation is less than 20cm, the same thickness of insulation can save more energy when placed on the inside of the wall than on the outside. When insulation thickness exceeds 20 cm, outside placement is more effective.

However, **taking into account the building costs and embedded carbon emissions, the design will incorporate 5cm of insulation positioned externally on the wall.** The addition of 5cm of insulation significantly decreases energy intensity. At this time, the insulation placed indoors (84.12 kWh/year/ ㎡) is slightly more energy-efficient than the insulation placed outside(84.18 kWh/year/ ㎡), but the difference is minimal. Installing insulation indoors will expand the insulated area and increase construction costs. When insulation exceeds 5 cm, the decrease in energy intensity is minimal.

Figure 3.1.28 Anual cooling load for the whole unit as a function of insulation thinckness and glazing type
Source: Created by author, 2024



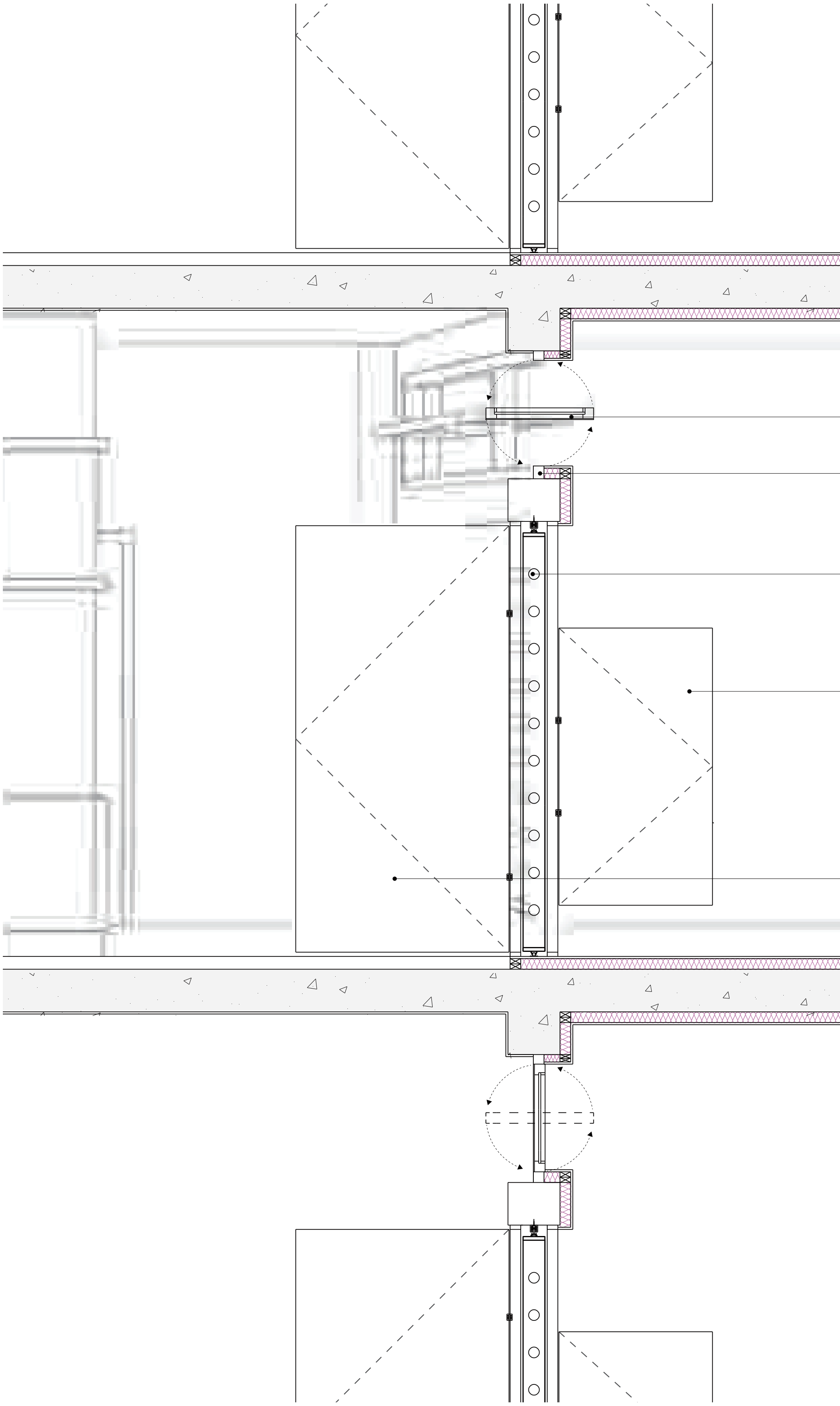


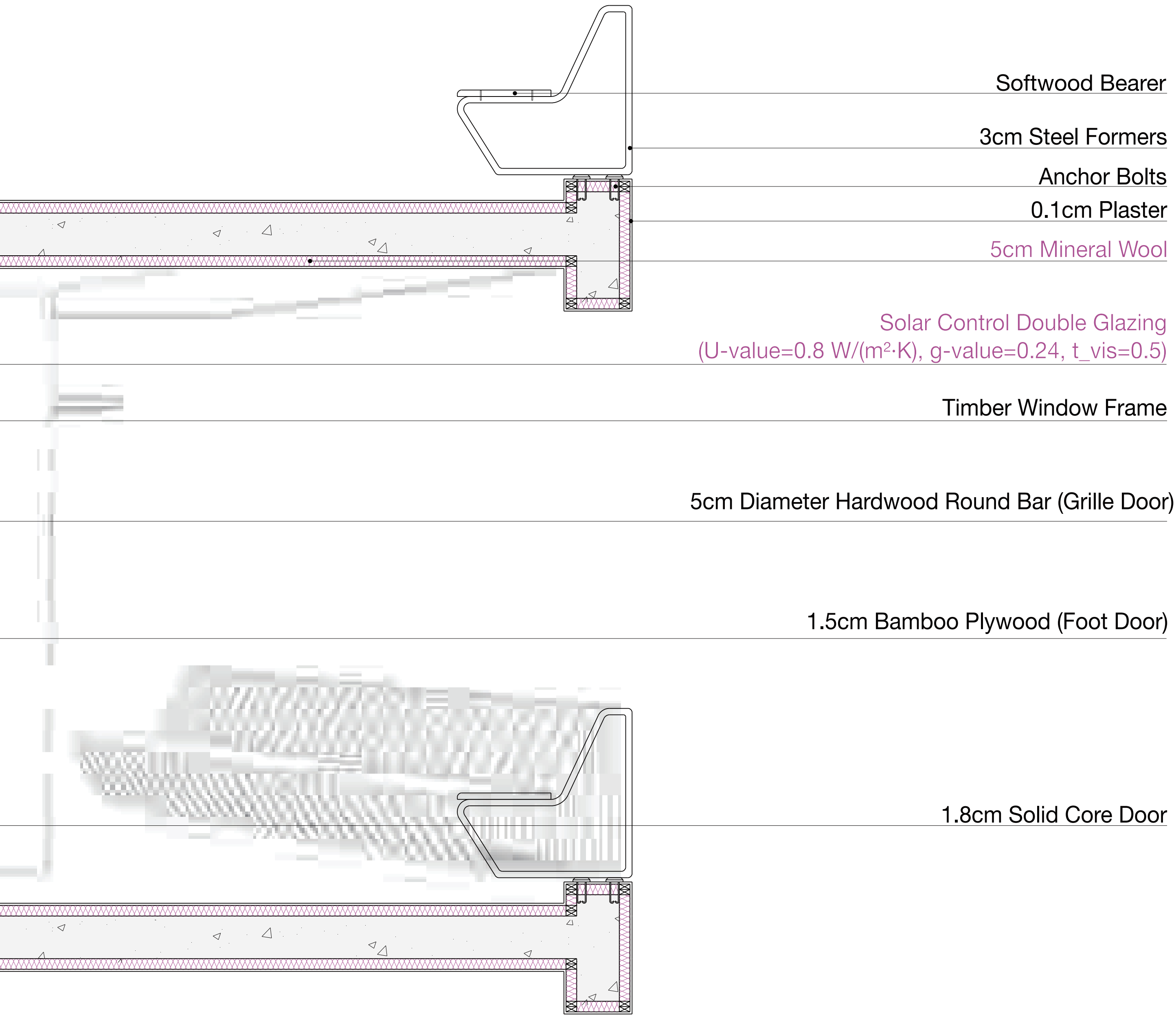
The simulation results indicate that a lower U-value for glass is not always better. When the g-value is the same, triple glazing actually requires a higher cooling load compared to single glazing. This suggests that compared to the U-value, the g-value has a much greater impact on cooling loads—especially in regions like Lingnan, where high humidity, frequent cloudy days, and dominant diffuse solar radiation are common. Since diffuse radiation comes from multiple directions, fixed shading devices aren't always effective at blocking it. That's why opting for low-g-value glass is a better approach for controlling solar heat gain and reducing cooling demand.

According to our analysis, **the best glazing option is double glazing with a U-value of 2.4 W/(m²K), g-value of 0.24, and visible light transmittance (t_vis) of 0.5.**

Figure 3.1.29 Detail section of the unit

Source: Created by author, 2024





Softwood Bearer
3cm Steel Formers
Anchor Bolts
0.1cm Plaster
5cm Mineral Wool
Solar Control Double Glazing
(U-value=0.8 W/(m²·K), g-value=0.24, t_vis=0.5)
Timber Window Frame
5cm Diameter Hardwood Round Bar (Grille Door)
1.5cm Bamboo Plywood (Foot Door)
1.8cm Solid Core Door

Figure 3.1.30: Thermal load balance of reference building
Source: Created by author, 2024
Software: Grasshopper, honeybee

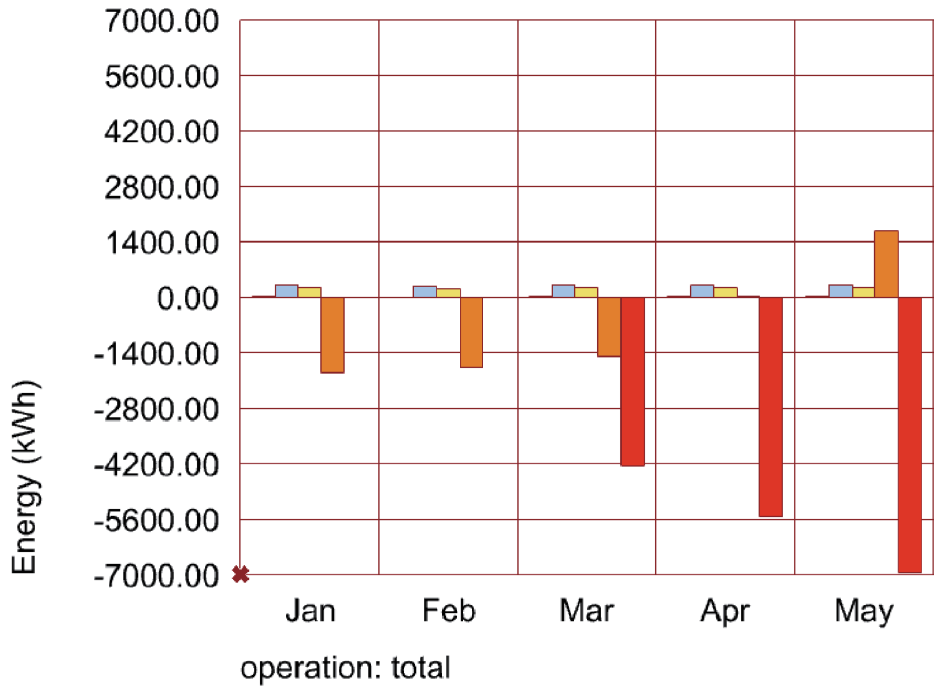
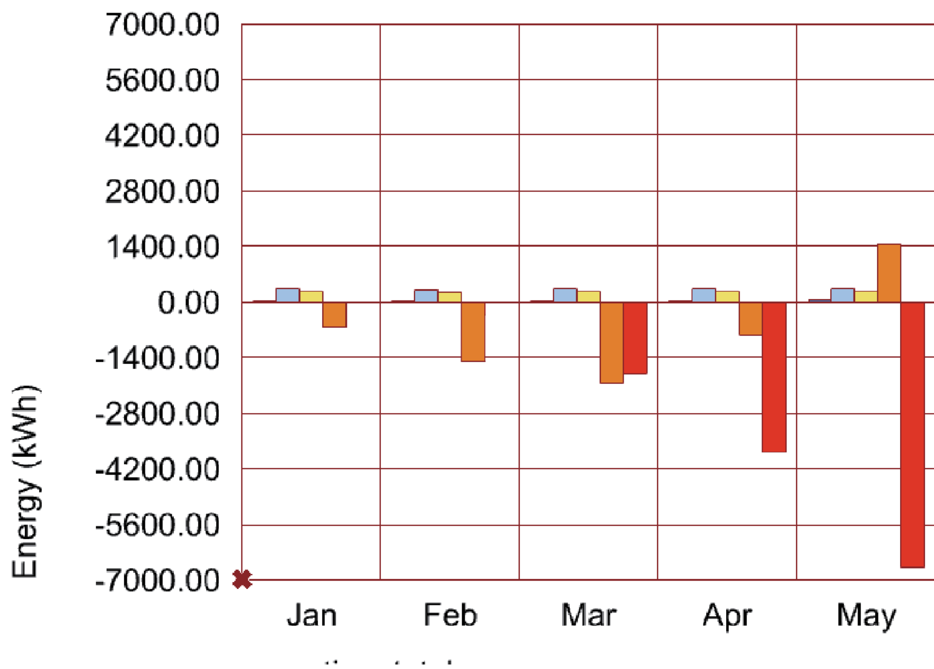
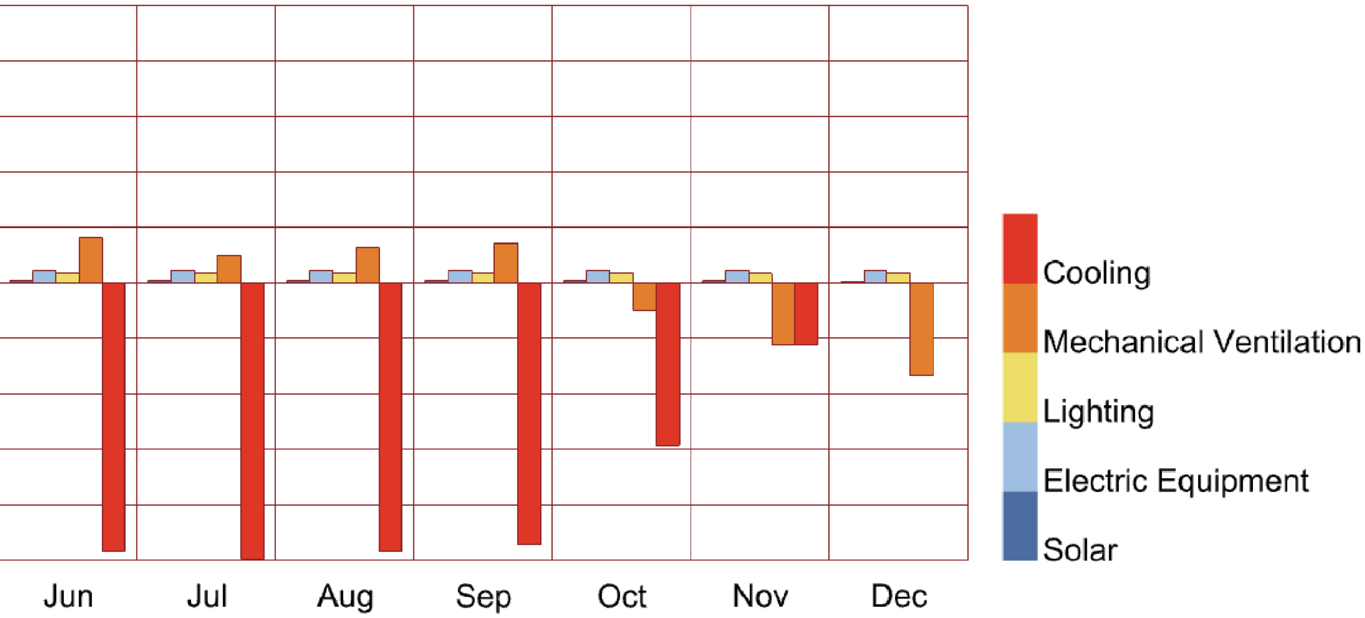


Figure 3.1.31: Thermal load balance of retrofited apartment
Source: Created by author, 2024
Software: Grasshopper, honeybee



(Exteral wall **without insulation**, glazing parameter: **u value=4 W/m^{2}K; shgc=0.55; t_vis=0.70**)



(Exteral wall **with 5cm insulation**, glazing parameter: **u value=2.4 W/m^{2}K; shgc=0.24; t_vis=0.50)**

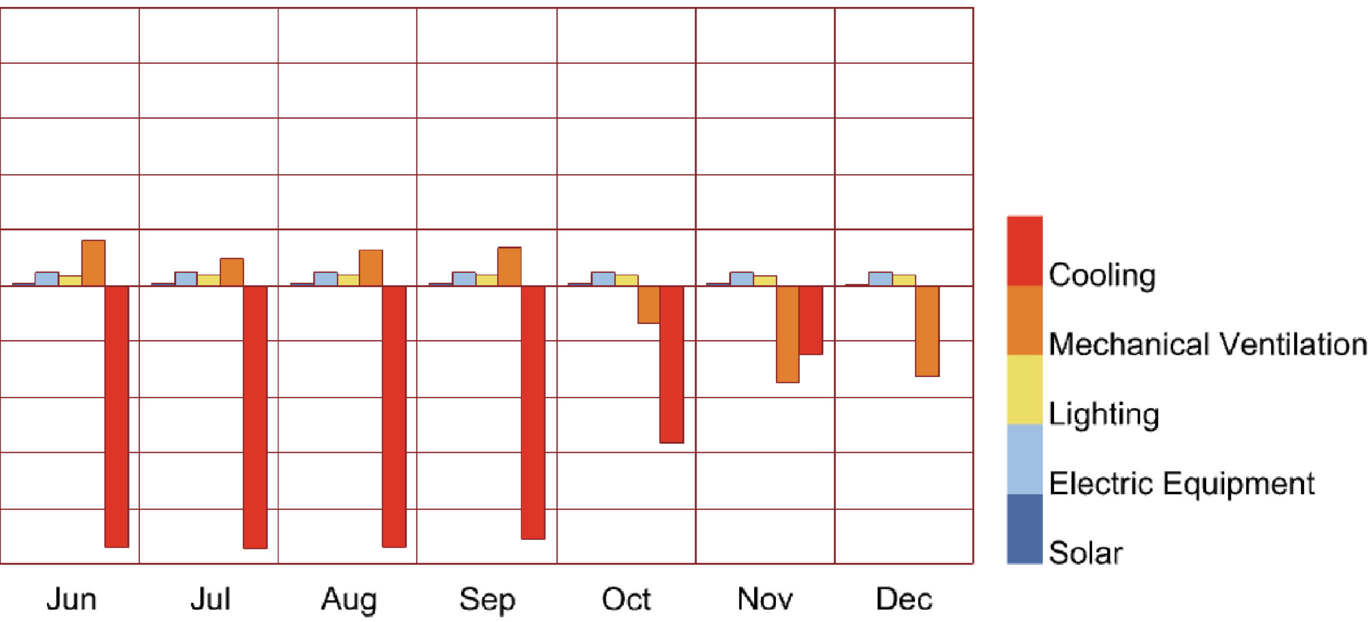
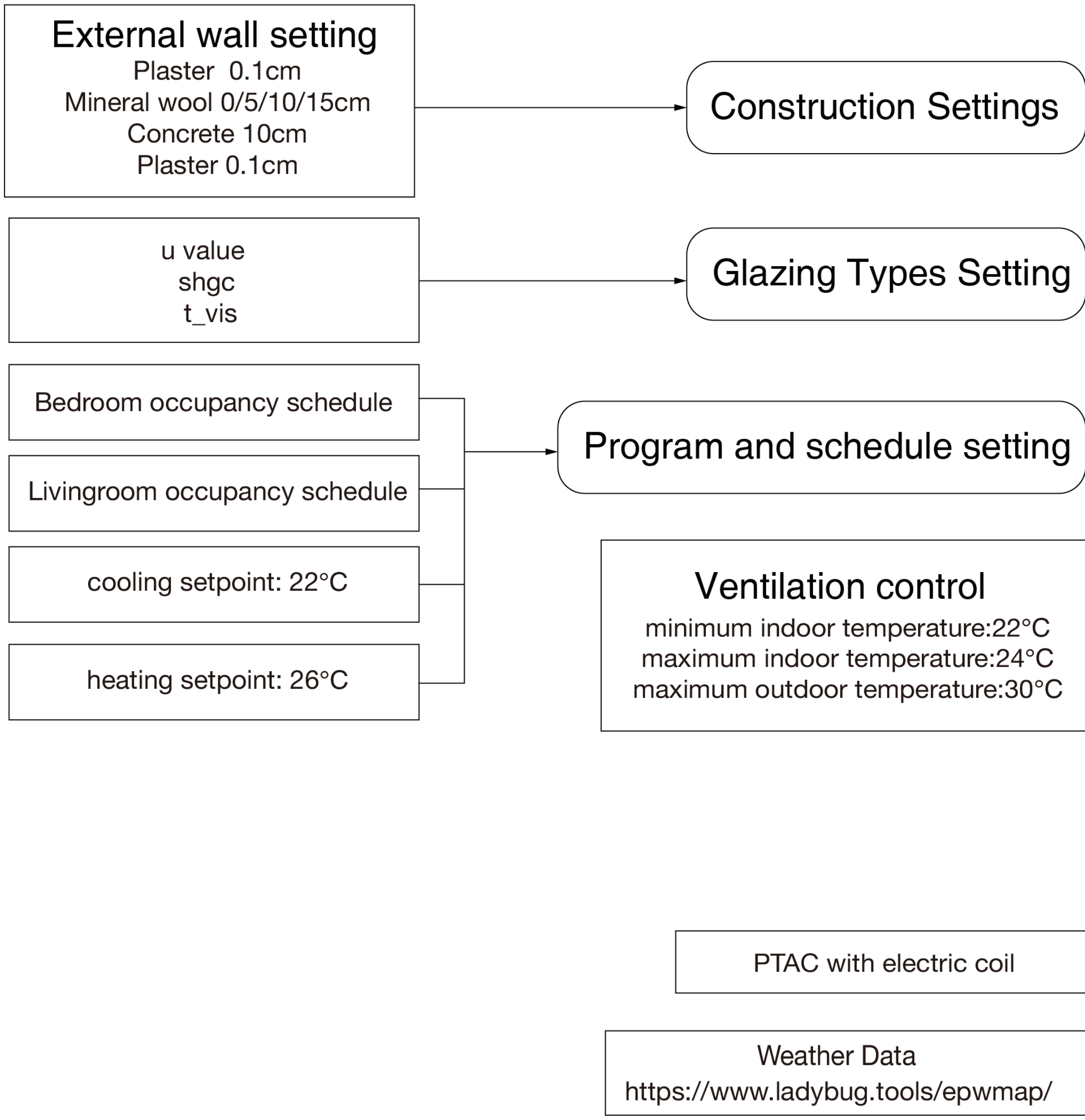
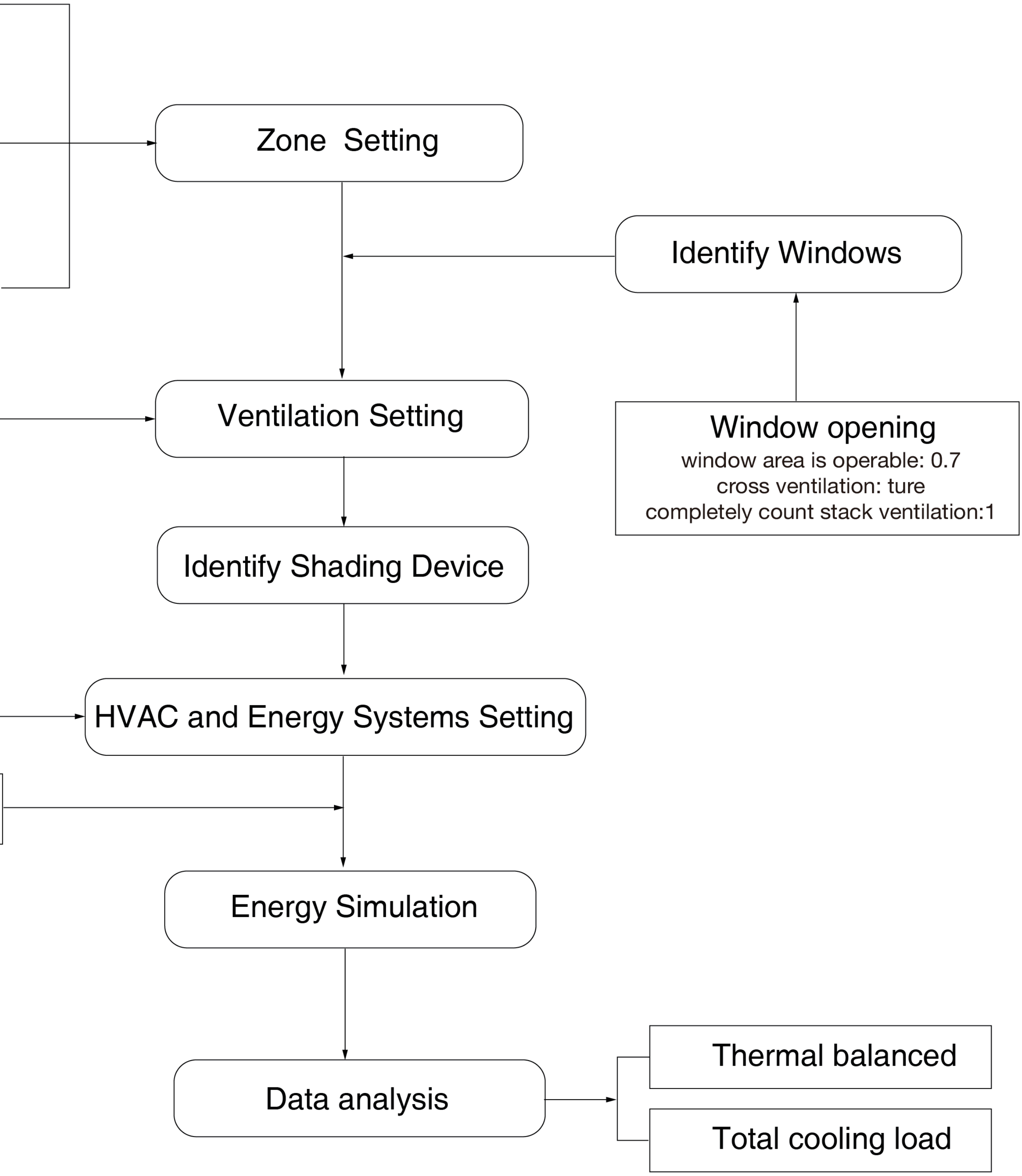


Figure 3.1.32 Workflow diagram of energy simulation based on honeybee software
Source: Created by author, 2024




Zone Setting
Identify Windows
Ventilation Setting
Window opening
window area is operable: 0.7
cross ventilation: ture
completely count stack ventilation:1
Identify Shading Device
HVAC and Energy Systems Setting
Energy Simulation
Data analysis
Thermal balanced
Total cooling load

3.1.7 Layout design of the typical floors

Figure 3.1.33 Exploded diagram of the typical floors

Source: Created by author, 2024

Based on the structural of the existing buildings. **The most apartments could be oriented northwest to southeast. This design lets summer breezes naturally pass through the apartment, removing extra heat to cooling the inside spaces.** This layout caters to the summer wind can helps us maximize natural ventilation and improve the indoor thermal comfort in warmer months.

Some areas of the exsiting floors were demolished to create wind shafts. Summer breezes pass through these air shafts, delivering cool air to each floor and then exhausting hot air through the outlets on the roof. This design produces a natural cooling system for the entire building.

In addition to maximizing ventilation, three alternative apartmennt models were designed based on the diversity of the city's population. The two-bedroom apartment is suitable for a couple with a child, the senior apartment is suitable for an elderly couple, and the single room is suitable for the young.

2-Bedrooms Apartment
(Single ventilation)

2-Bedrooms Apartment
(Cross ventilation)

Senior apartments

Single Room

Sharing Kitchen and Laundry

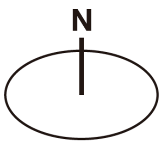
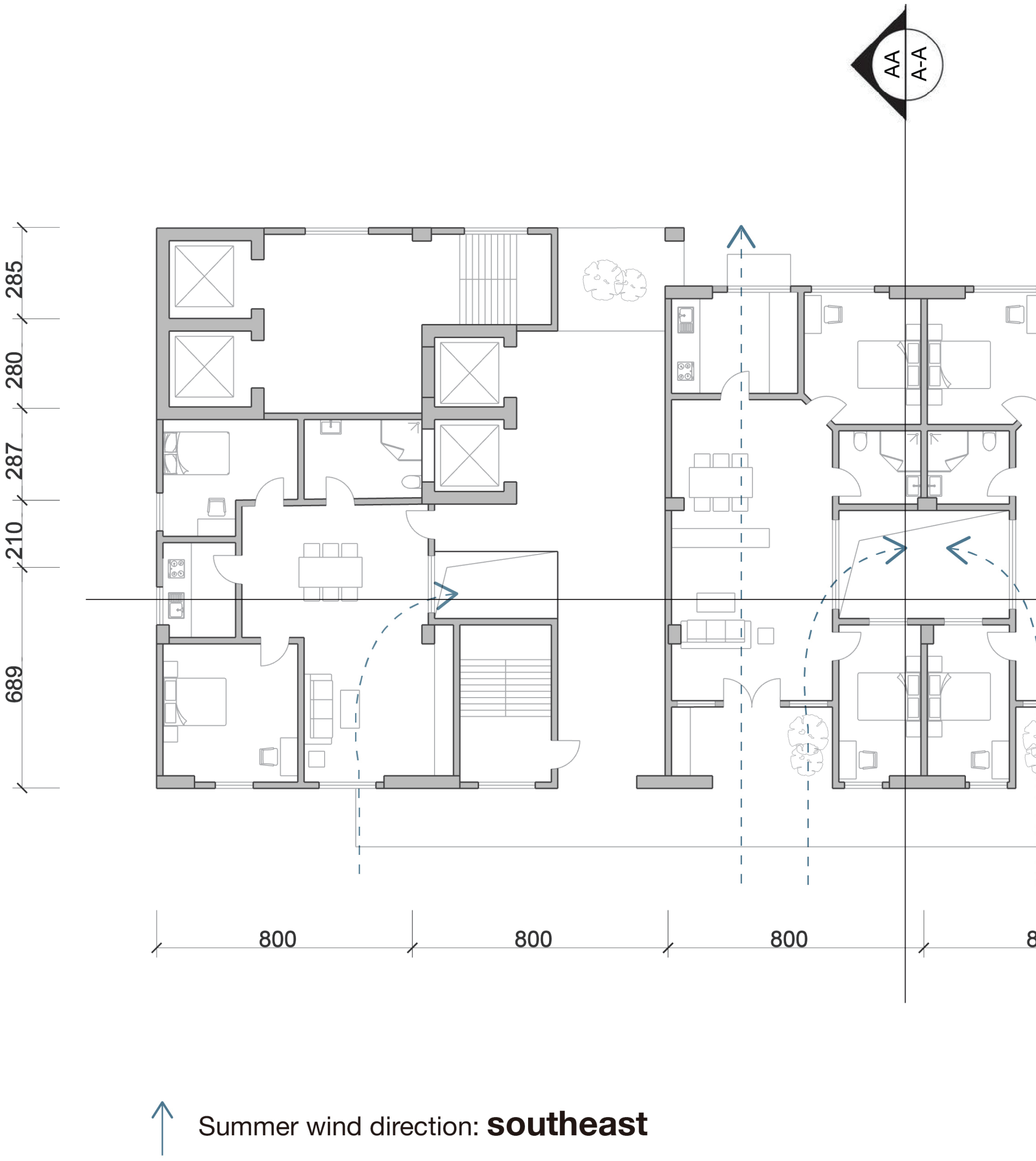


Figure 3.1.34 Typical floor plan of 2 bedrooms apartment

Source: Created by author, 2024

Unit: cm



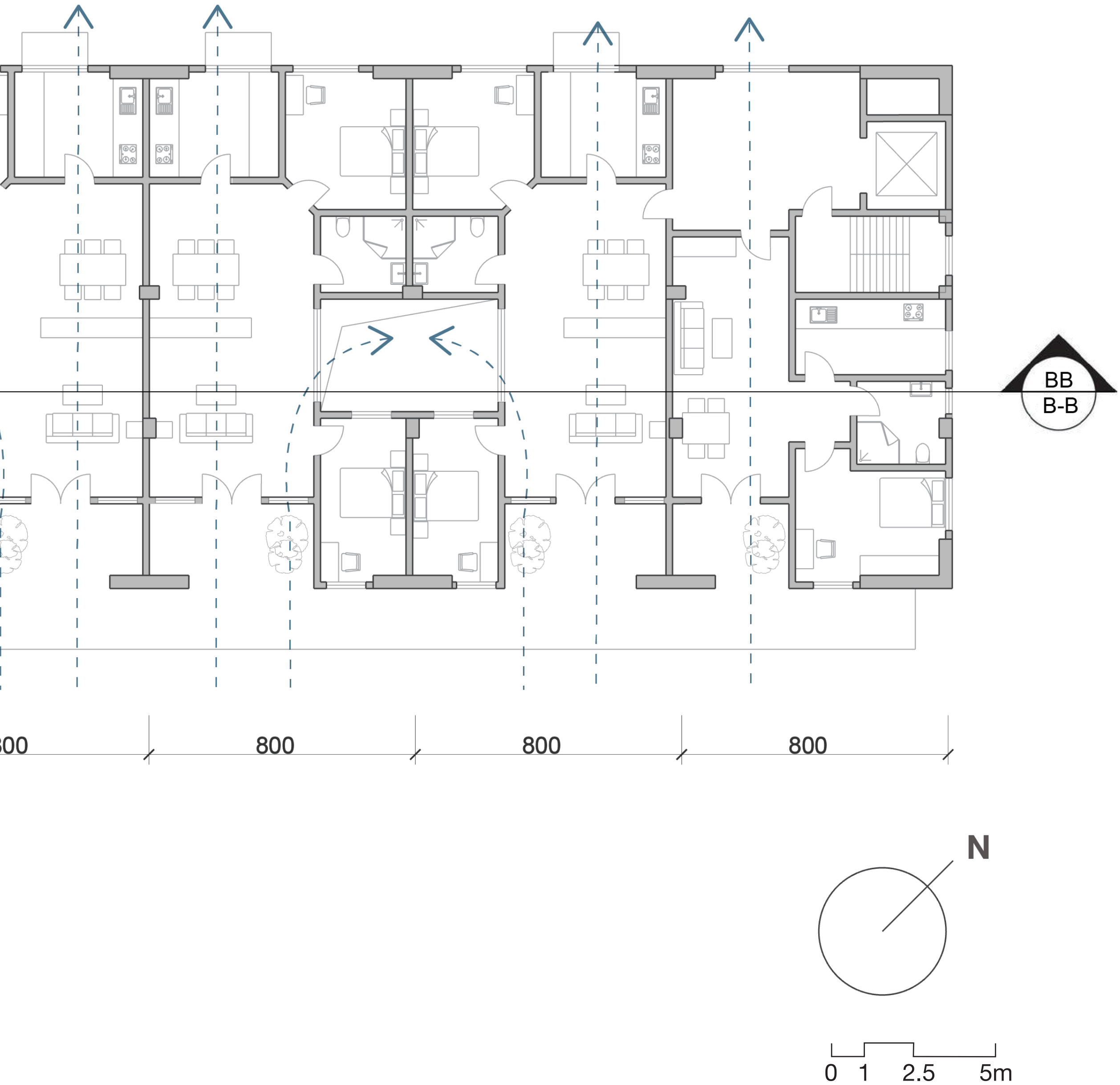
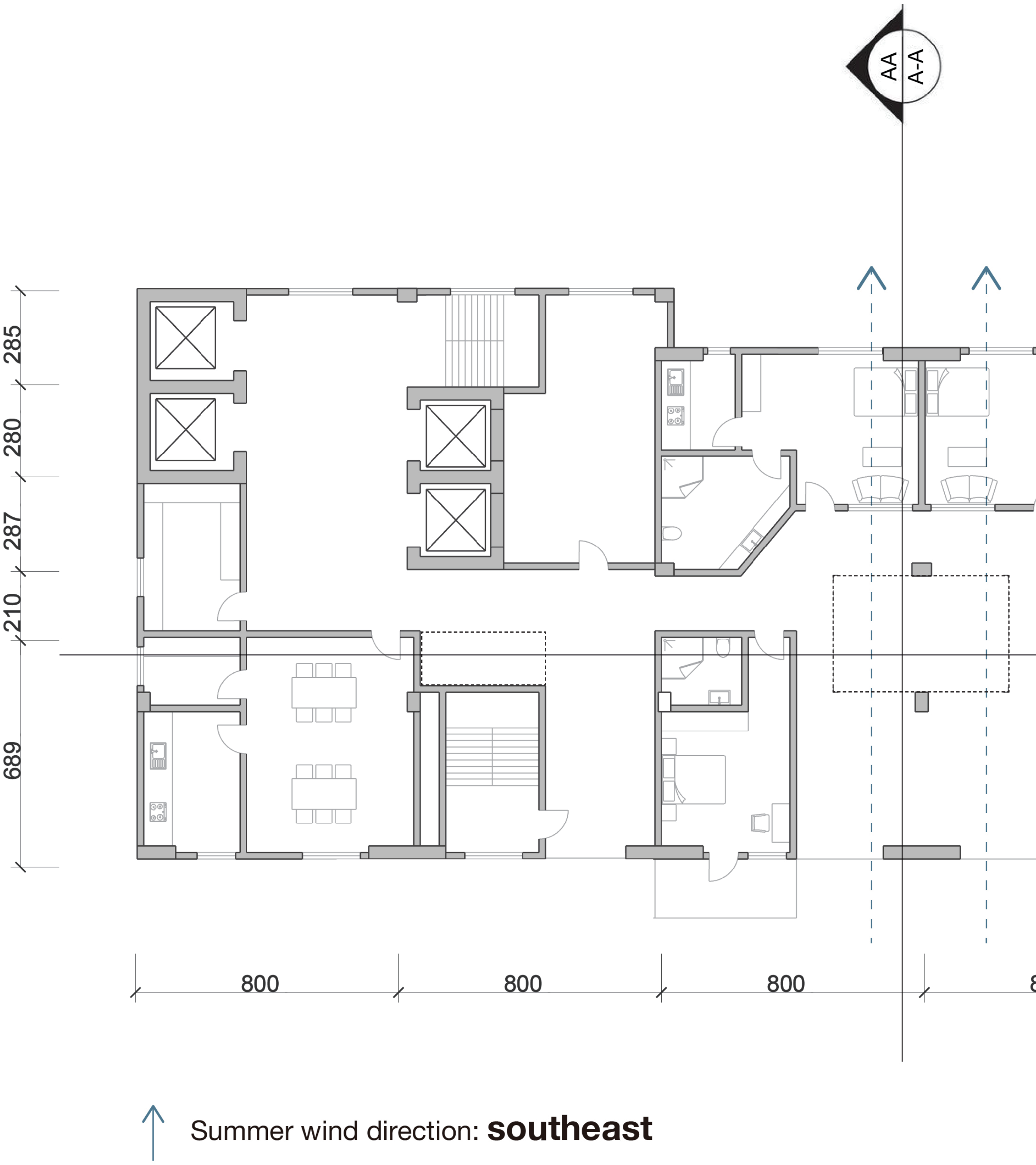

BB
B-B
800
800
800
800
N
0
1
2.5
5m

Figure 3.1.35 Typical floor plan of Senior apartment and single room

Source: Created by author, 2024

Unit: cm

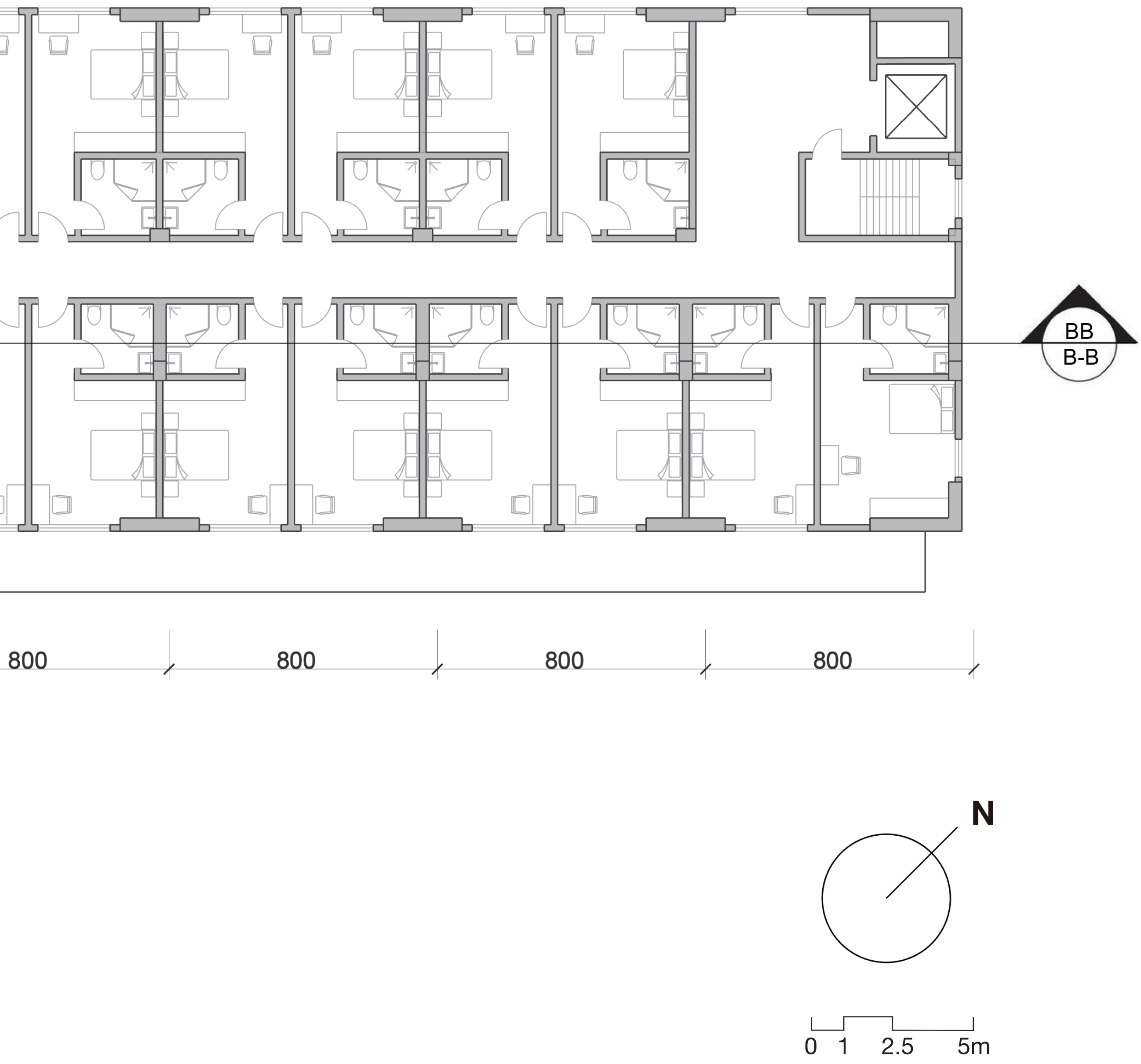



BB
B-B
800
800
800
800
N
0
1
2.5
5m

Figure 3.1.36 Typical floor plan of hotel rooms

Source: Created by author, 2024

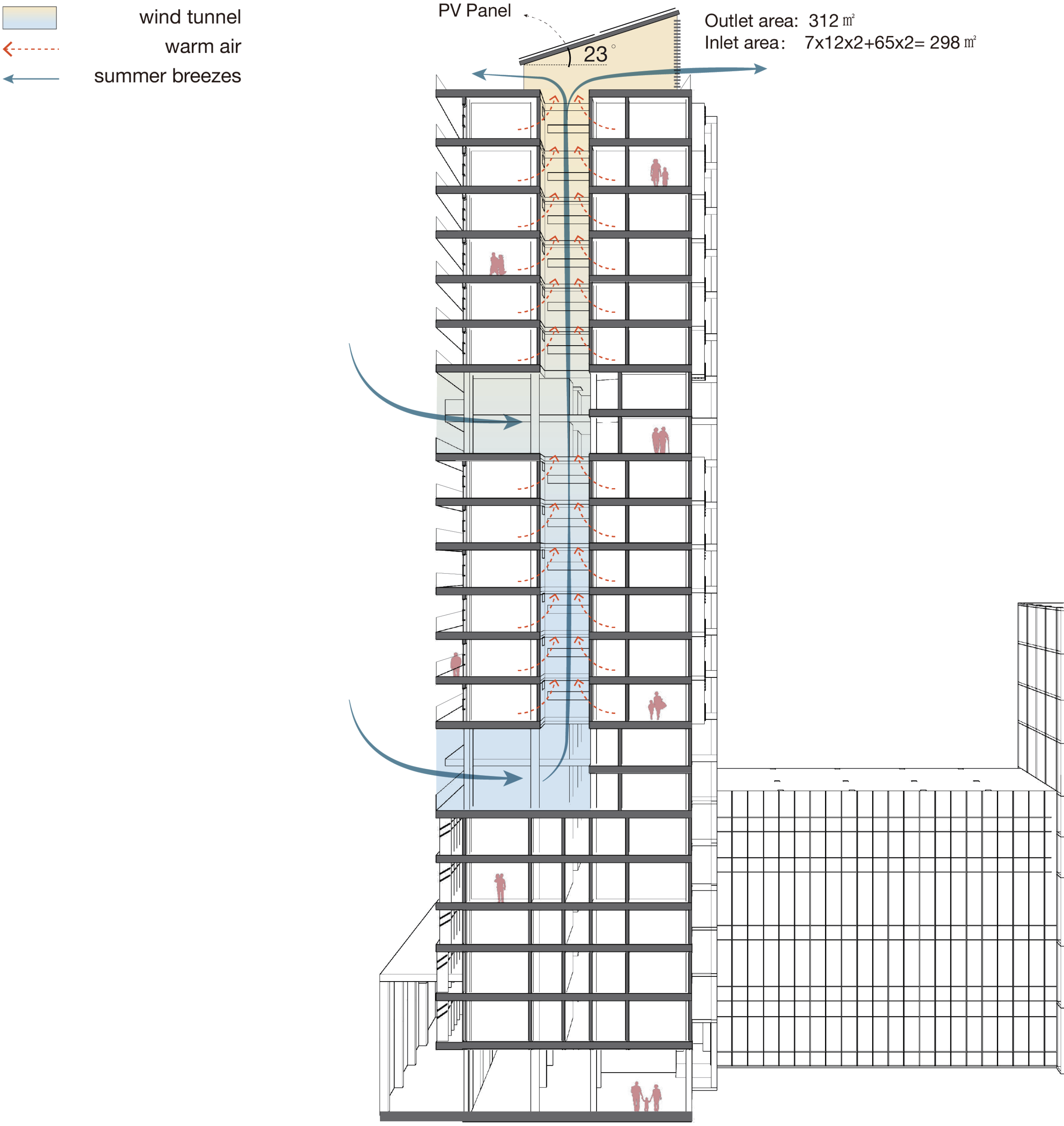
Unit: cm


BB
B-B
800
800
800
800
N
0
1
2.5
5m

3.1.8 Natural ventiation design of the building

Figure 3.1.37 Pespective section A-A of the building

Source: Created by author, 2024



22F Roof garden

21F 2-Bedrooms apartment

20F 2-Bedrooms apartment

19F 2-Bedrooms apartment

18F 2-Bedrooms apartment

17F 2-Bedrooms apartment

16F 2-Bedrooms apartment

15F Senior apartment & Single apartment

14F Senior apartment & Single apartment

13F 2-Bedrooms apartment

12F 2-Bedrooms apartment

11F 2-Bedrooms apartment

10F 2-Bedrooms apartment

9F 2-Bedrooms apartment

8F 2-Bedrooms apartment

7F Senior apartment & Single apartment

6F Senior apartment & Single apartment

5F Hotel room

4F Hotel room

3F Hotel room

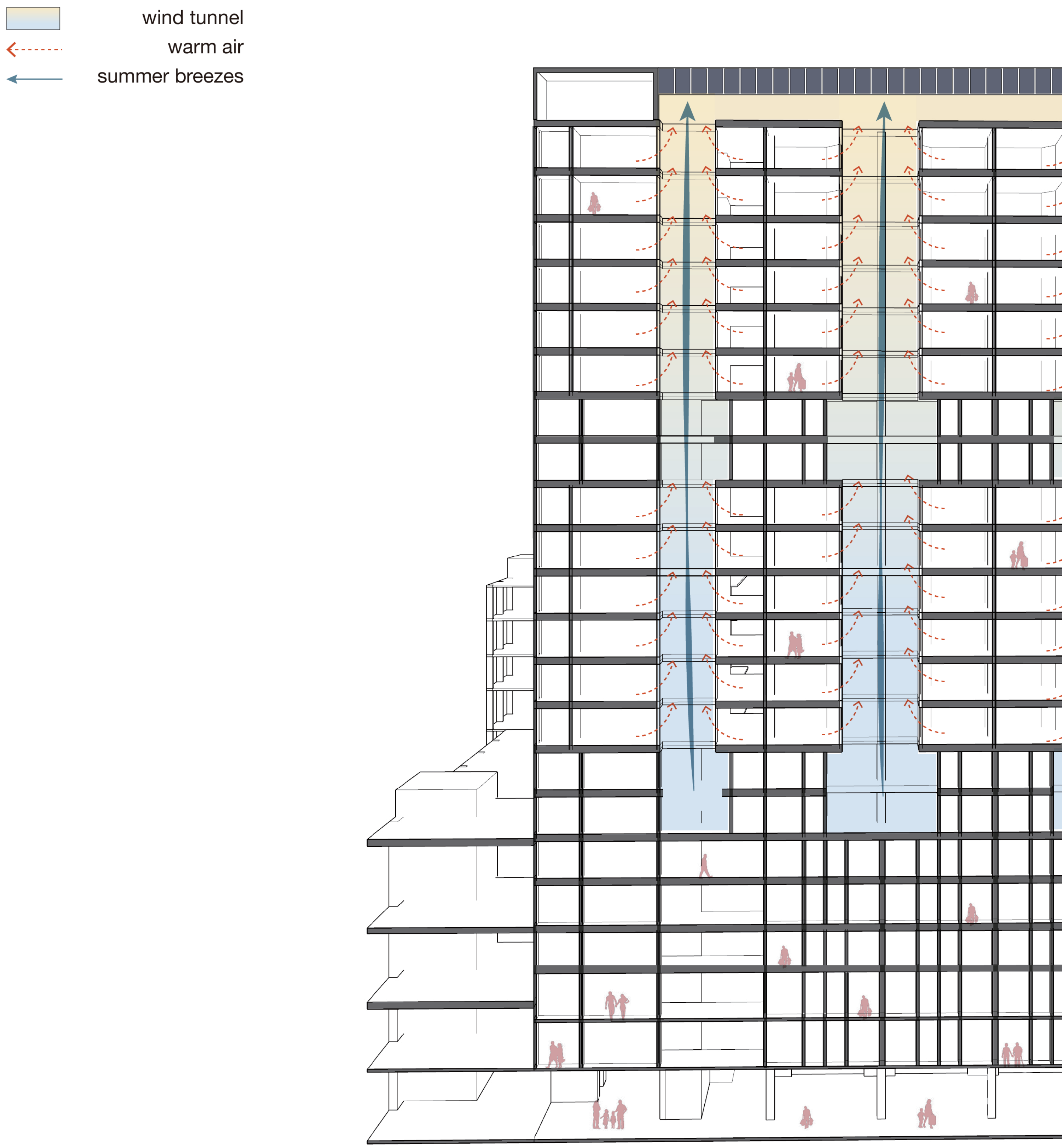
2F Hotel room

1F Hotel room

0F Reception

Figure 3.1.38 Pespective section B-B of the building

Source: Created by author, 2024




PV Panel
22F Roof garden
21F 2-Bedrooms apartment
20F 2-Bedrooms apartment
19F 2-Bedrooms apartment
18F 2-Bedrooms apartment
17F 2-Bedrooms apartment
16F 2-Bedrooms apartment
15F Senior apartment & Single apartment
14F Senior apartment & Single apartment
13F 2-Bedrooms apartment
12F 2-Bedrooms apartment
11F 2-Bedrooms apartment
10F 2-Bedrooms apartment
9F 2-Bedrooms apartment
8F 2-Bedrooms apartment
7F Senior apartment & Single apartment
6F Senior apartment & Single apartment
5F Hotel room
4F Hotel room
3F Hotel room
2F Hotel room
1F Hotel room
0F Reception
wind tunnel
warm air
summer breezes

3.1.9 Facade design of the building

Figure 3.1.39 Southeast facade of the building
Source: Created by author, 2024

22F Roof garden

21F 2-Bedrooms apartment

20F 2-Bedrooms apartment

19F 2-Bedrooms apartment

18F 2-Bedrooms apartment

17F 2-Bedrooms apartment

16F 2-Bedrooms apartment

15F Senior apartment & Single apartment

14F Senior apartment & Single apartment

13F 2-Bedrooms apartment

12F 2-Bedrooms apartment

11F 2-Bedrooms apartment

10F 2-Bedrooms apartment

9F 2-Bedrooms apartment

8F 2-Bedrooms apartment

7F Senior apartment & Single apartment

6F Senior apartment & Single apartment

5F Hotel room

4F Hotel room

3F Hotel room

2F Hotel room

1F Hotel room

0F Reception

Figure 3.1.40 Northwest facade of the building

Source: Created by author, 2024

22F Roof garden

21F 2-Bedrooms apartment

20F 2-Bedrooms apartment

19F 2-Bedrooms apartment

18F 2-Bedrooms apartment

17F 2-Bedrooms apartment

16F 2-Bedrooms apartment

15F Senior apartment & Single apartment

14F Senior apartment & Single apartment

13F 2-Bedrooms apartment

12F 2-Bedrooms apartment

11F 2-Bedrooms apartment

10F 2-Bedrooms apartment

9F 2-Bedrooms apartment

8F 2-Bedrooms apartment

7F Senior apartment & Single apartment

6F Senior apartment & Single apartment

5F Hotel room

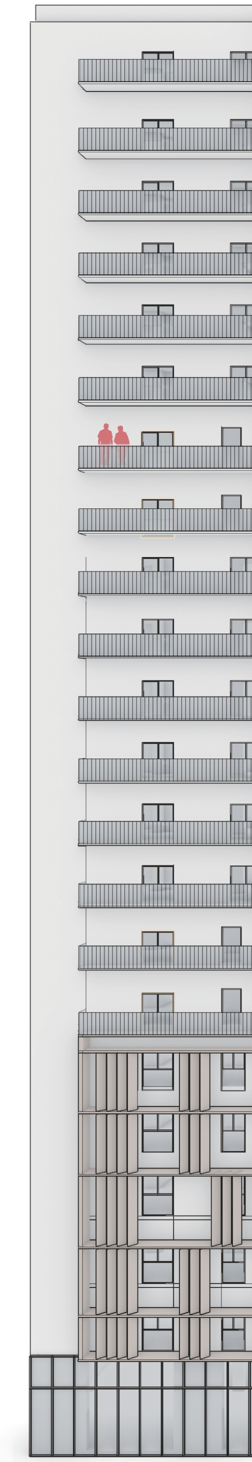
4F Hotel room

3F Hotel room

2F Hotel room

1F Hotel room

0F Reception



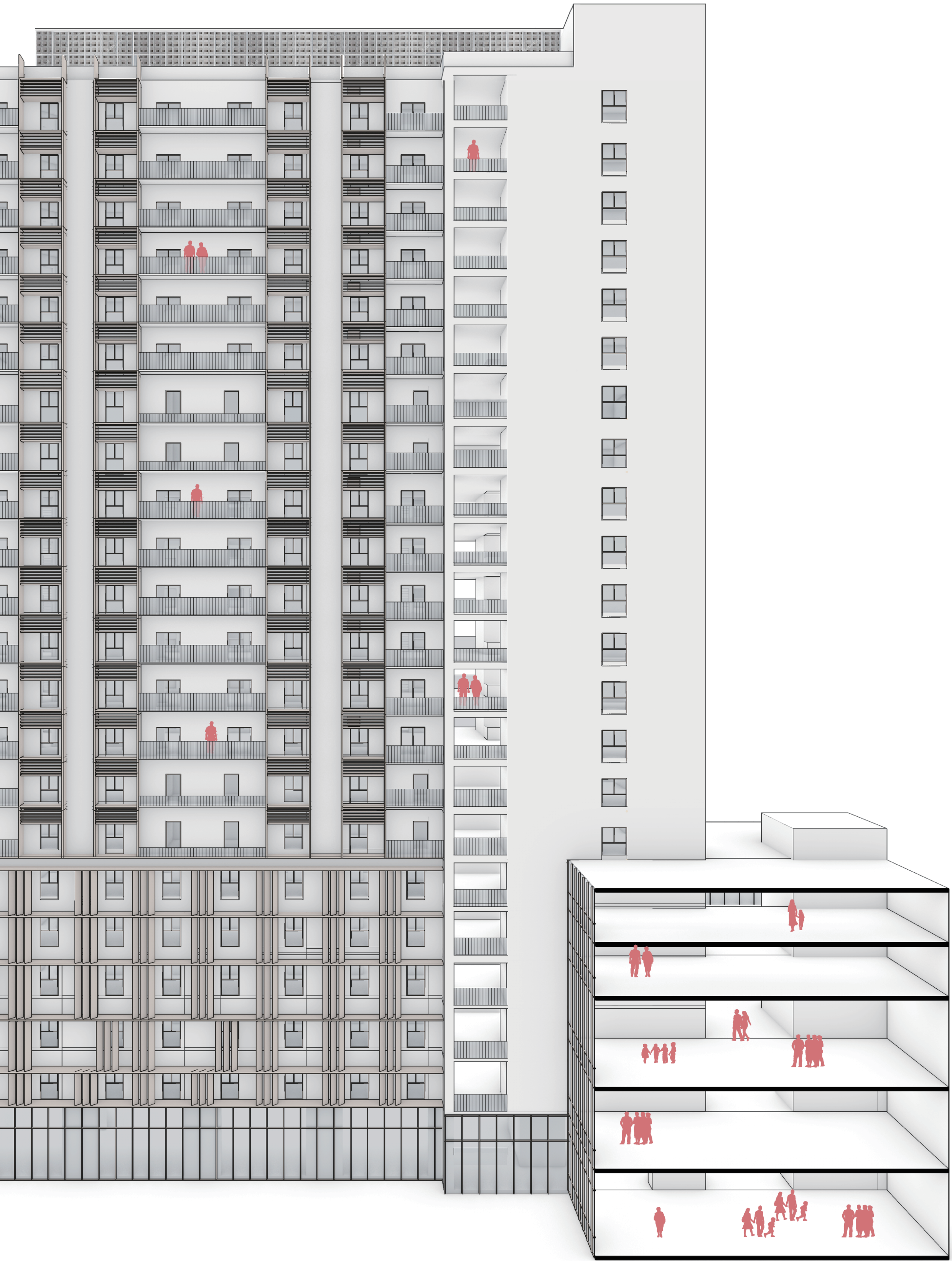
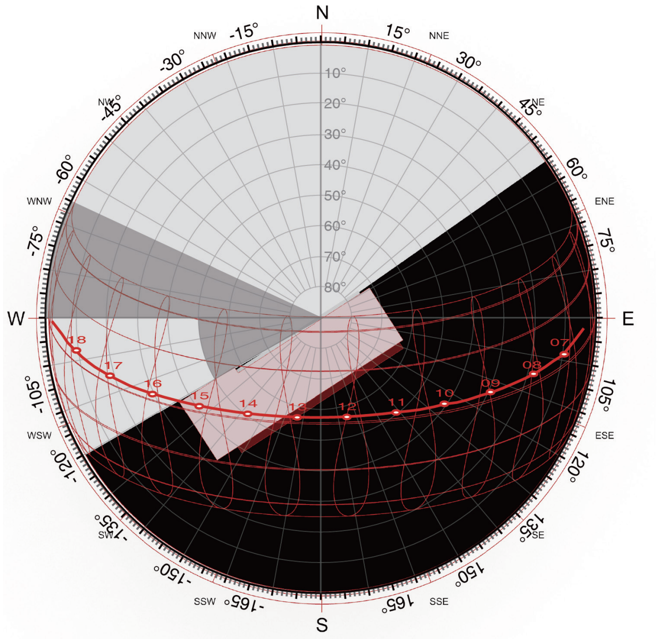


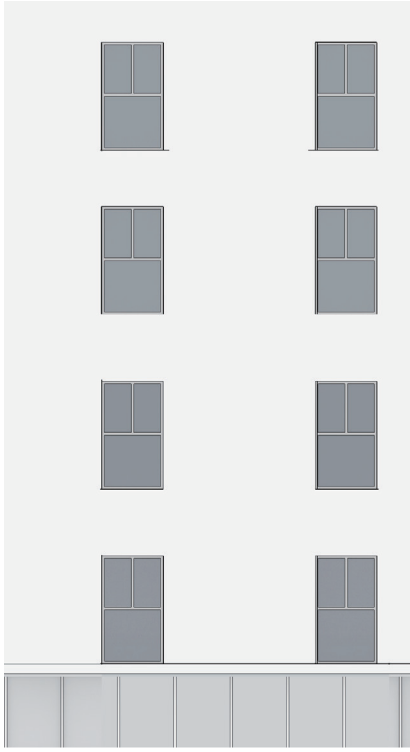
Figure 3.1.41 Shading devices design of the Northwest Hotel Room

Source: Created by author, 2024

Software: Ladybug,grasshopper

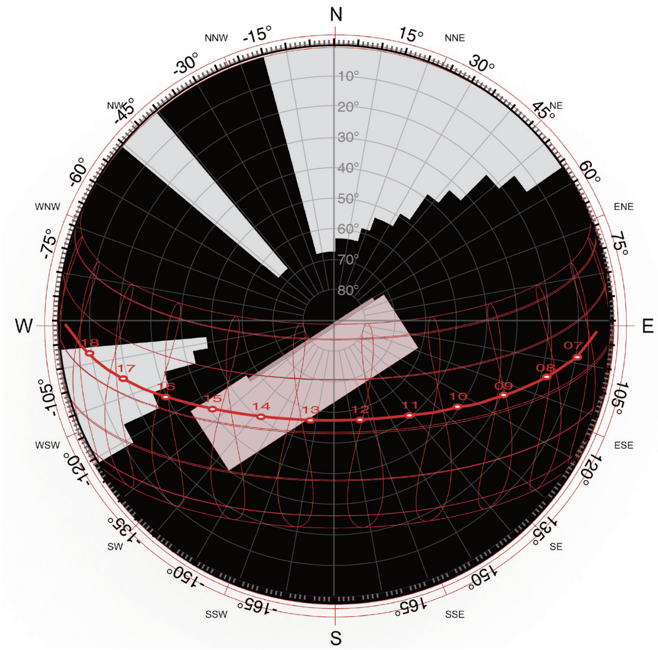
Existing





The area could be shaded by shading devices

Post-retrofitting



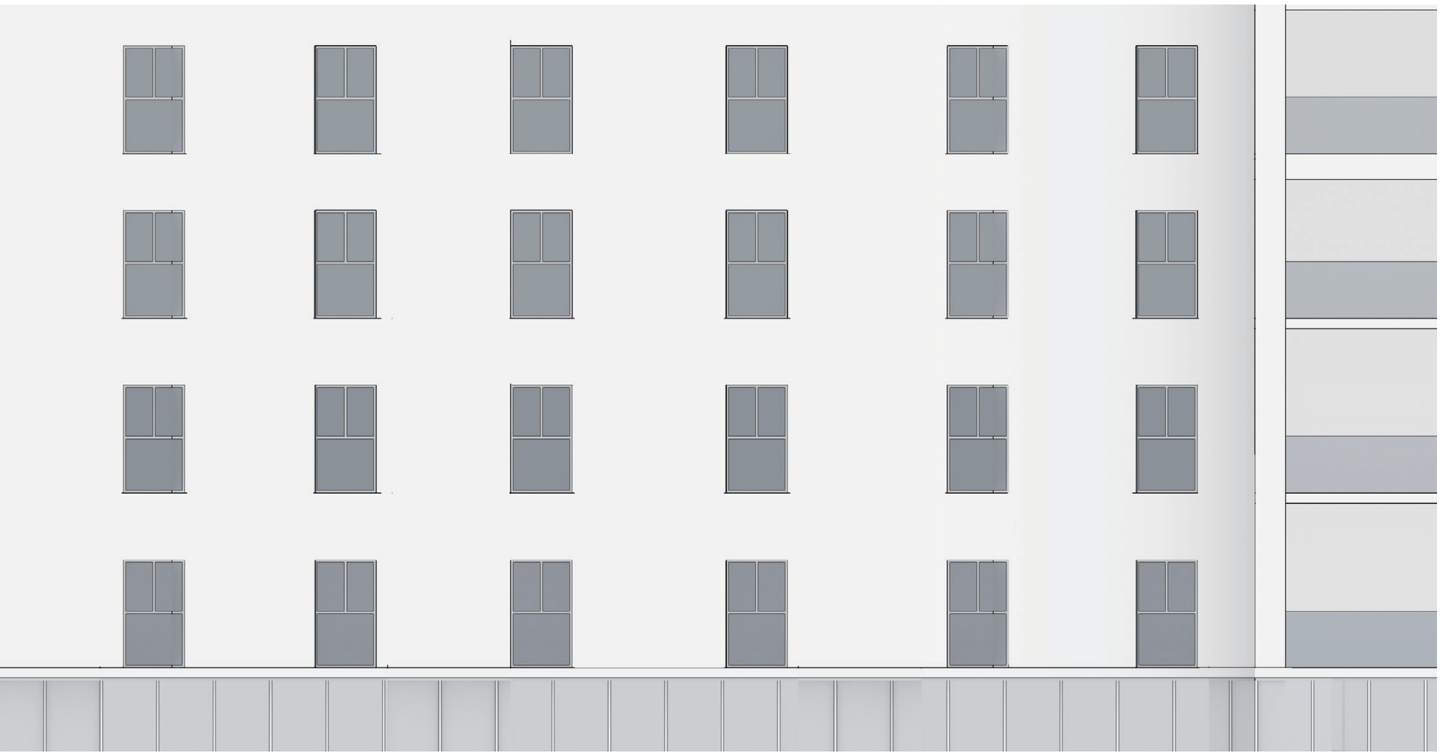
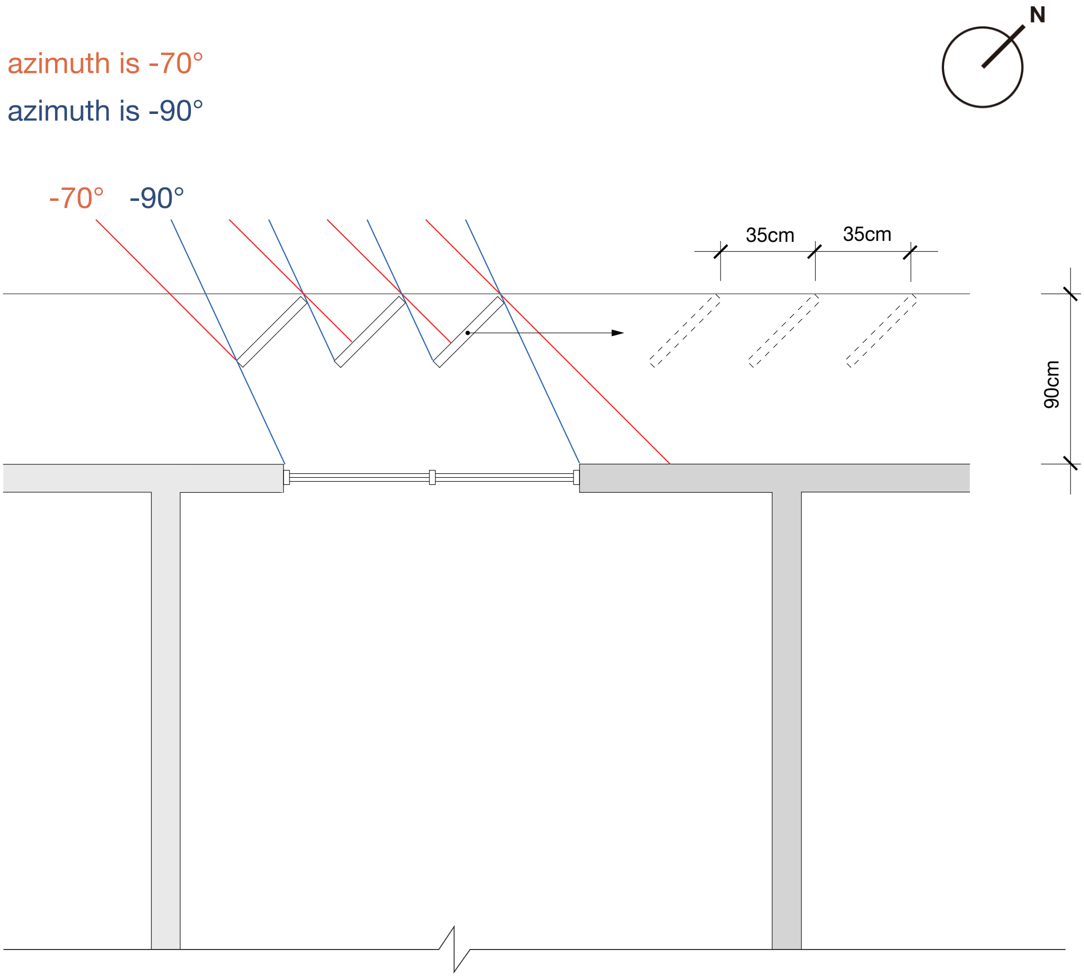


Figure 3.1.42 The plan of shading devices design in Northwest hotel room facade
Source: Created by author, 2024
Unit: cm

The solar azimuth is -70°
The solar azimuth is -90°



For the hotel room in the northwest, there are no shading device for the existing building, which could receive a lot of direct sunlight in the afternoon. Considering this situation, the eggcrate shading design method was adopted in the design of shading devices. **The fixed overhang (90cm) can block the sunlight with a solar altitude angle of 55° -90°, and the movable vertical fins can be used to block the sunlight when the sun is at a lower altitude in the evening near sunset to prevent glare（solar azimuth from -70° to -90°).**

Figure 3.1.43 The section of shading devices design in Northwest hotel room facade

Source: Created by author, 2024

Unit: cm

Solar altitude angle is 55° in summer

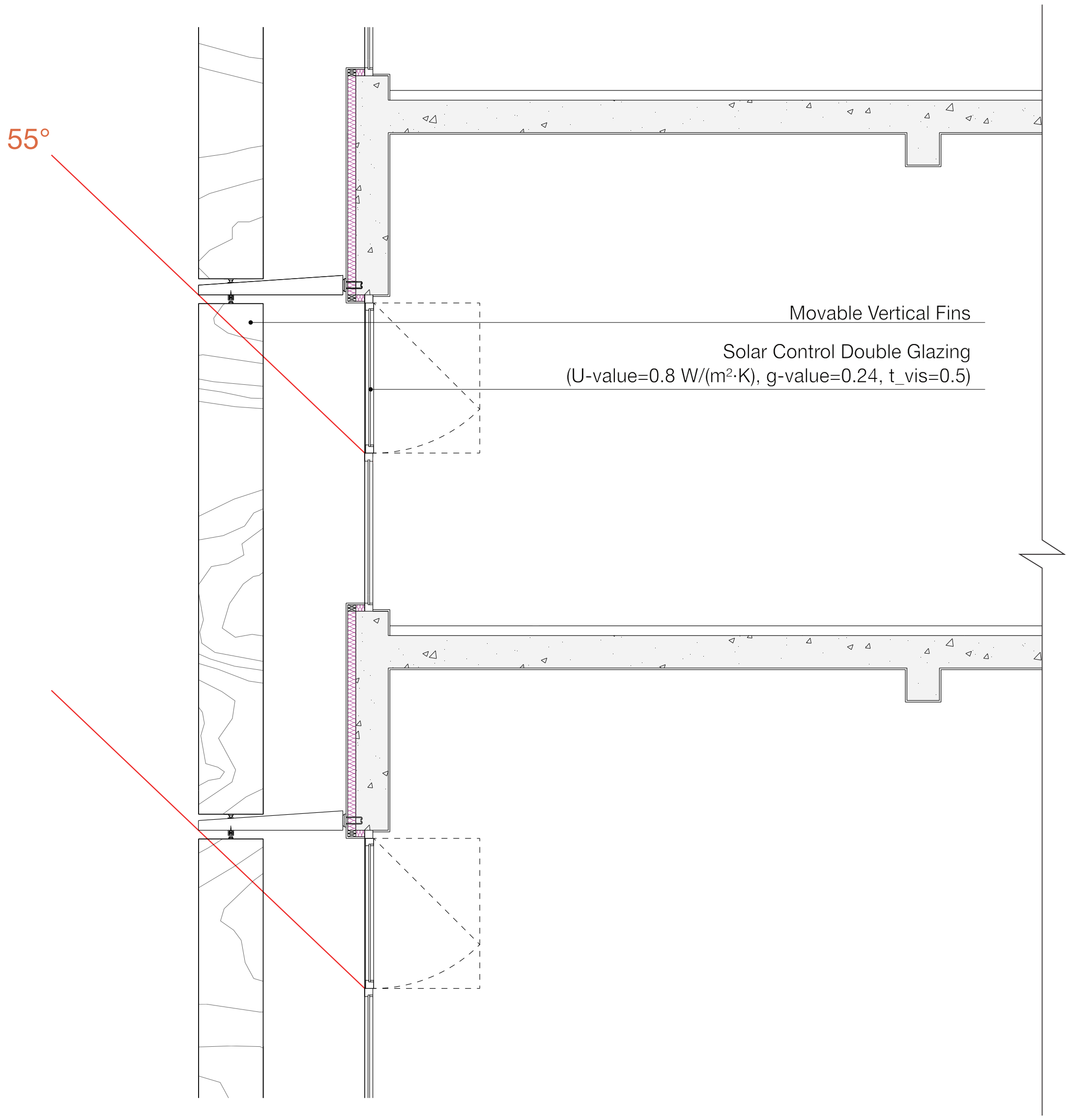
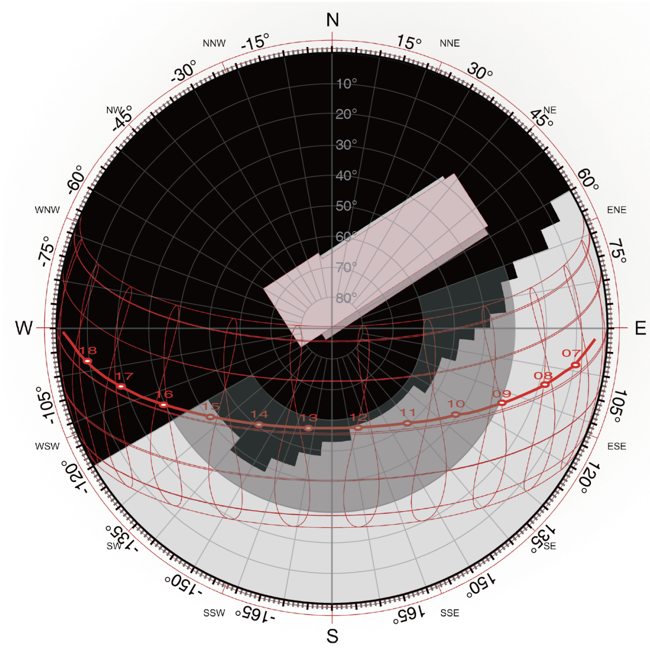


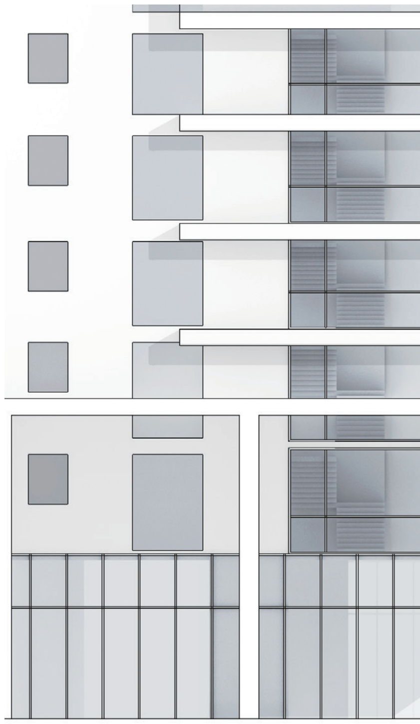
Figure 3.1.44 Shading Devices Design of the Southest Hotel room

Source: Created by author, 2024

Software: Ladybug,grasshopper

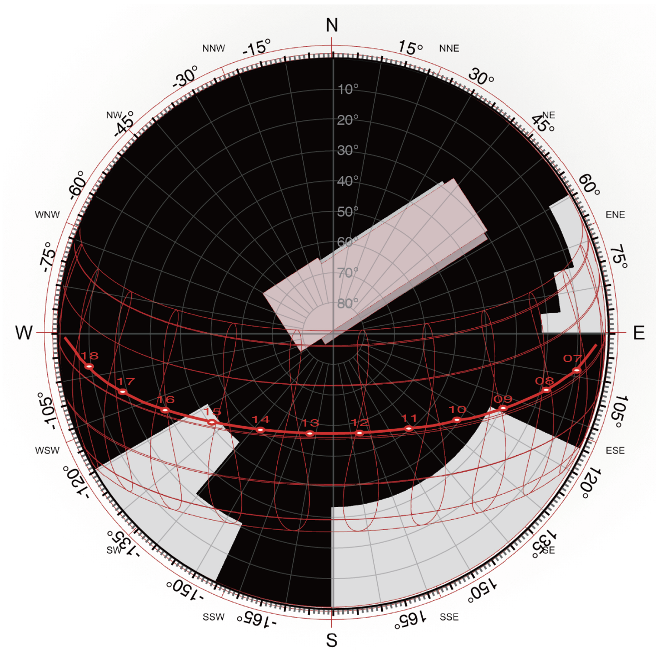
Existing

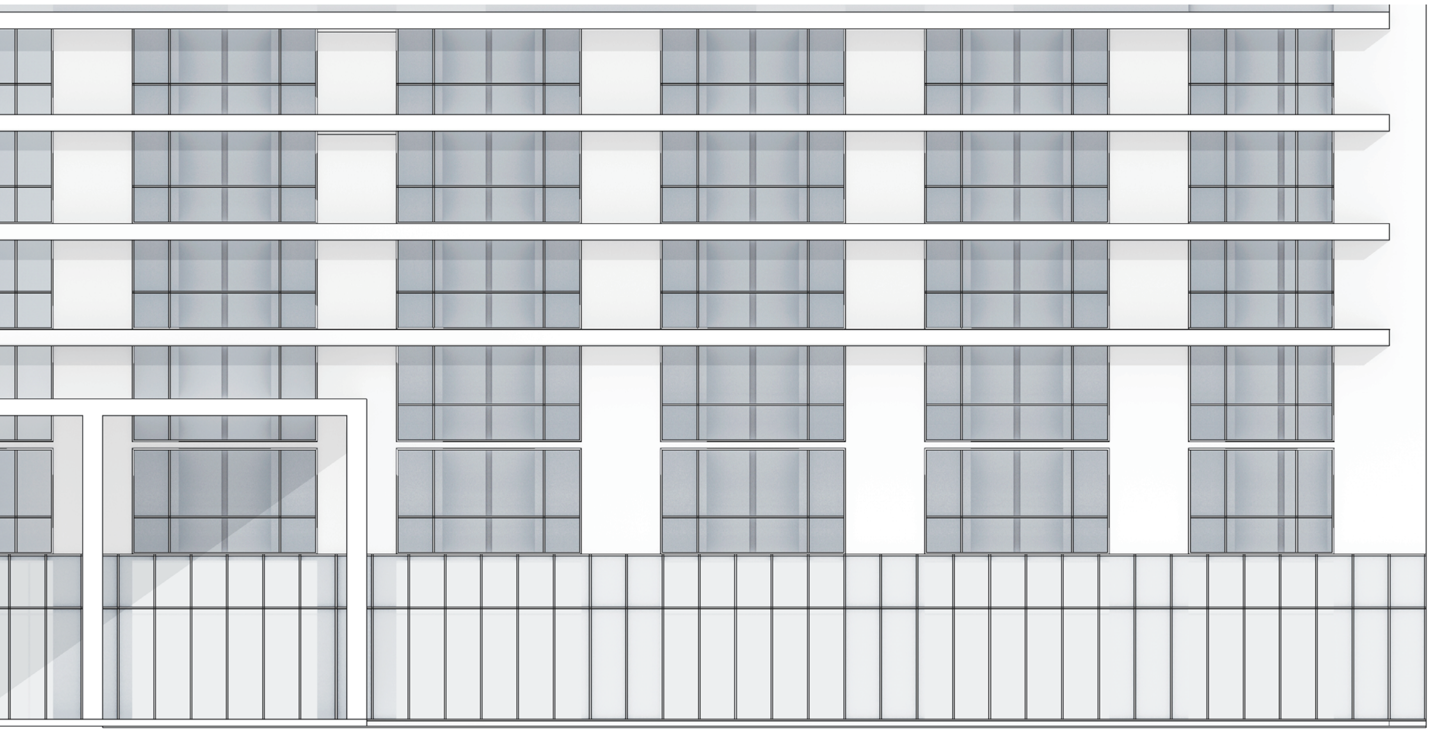




The area could be shaded by shading devices

Post-retrofitting





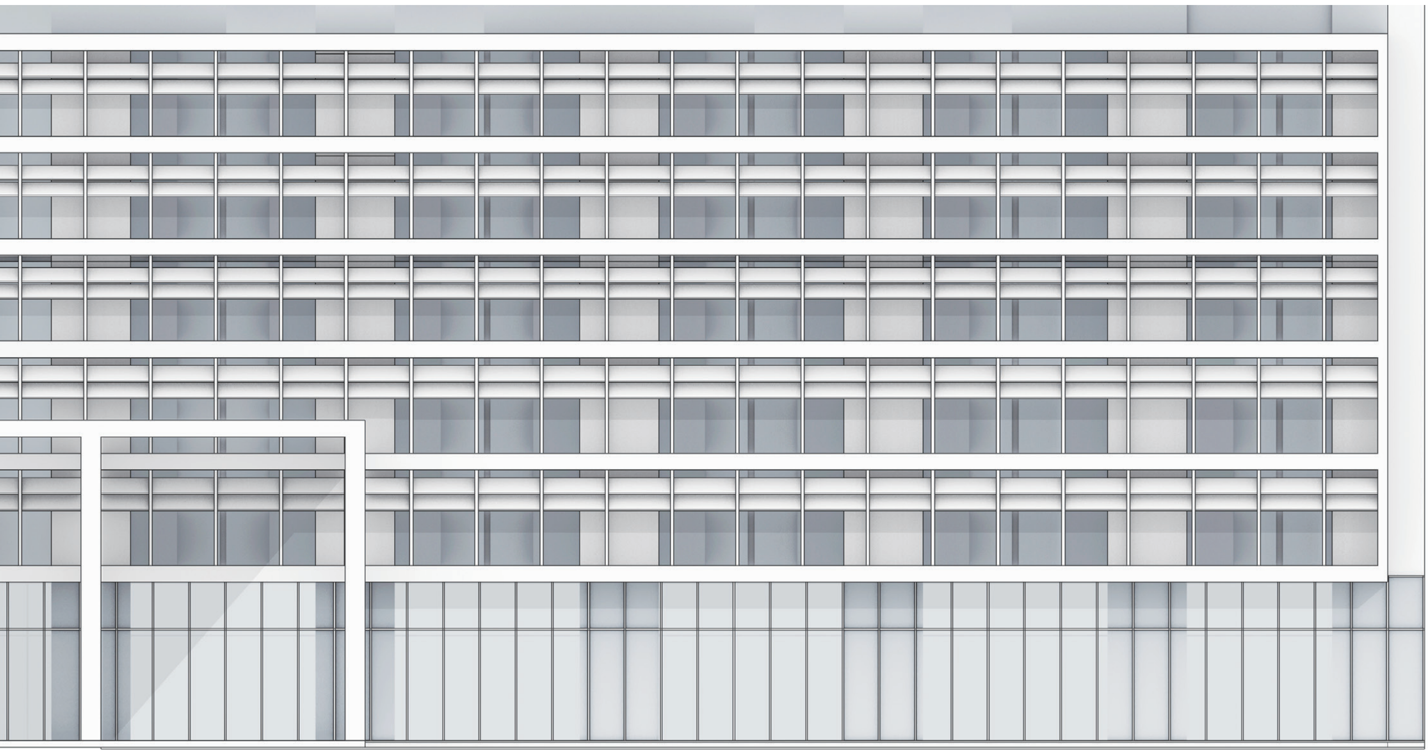
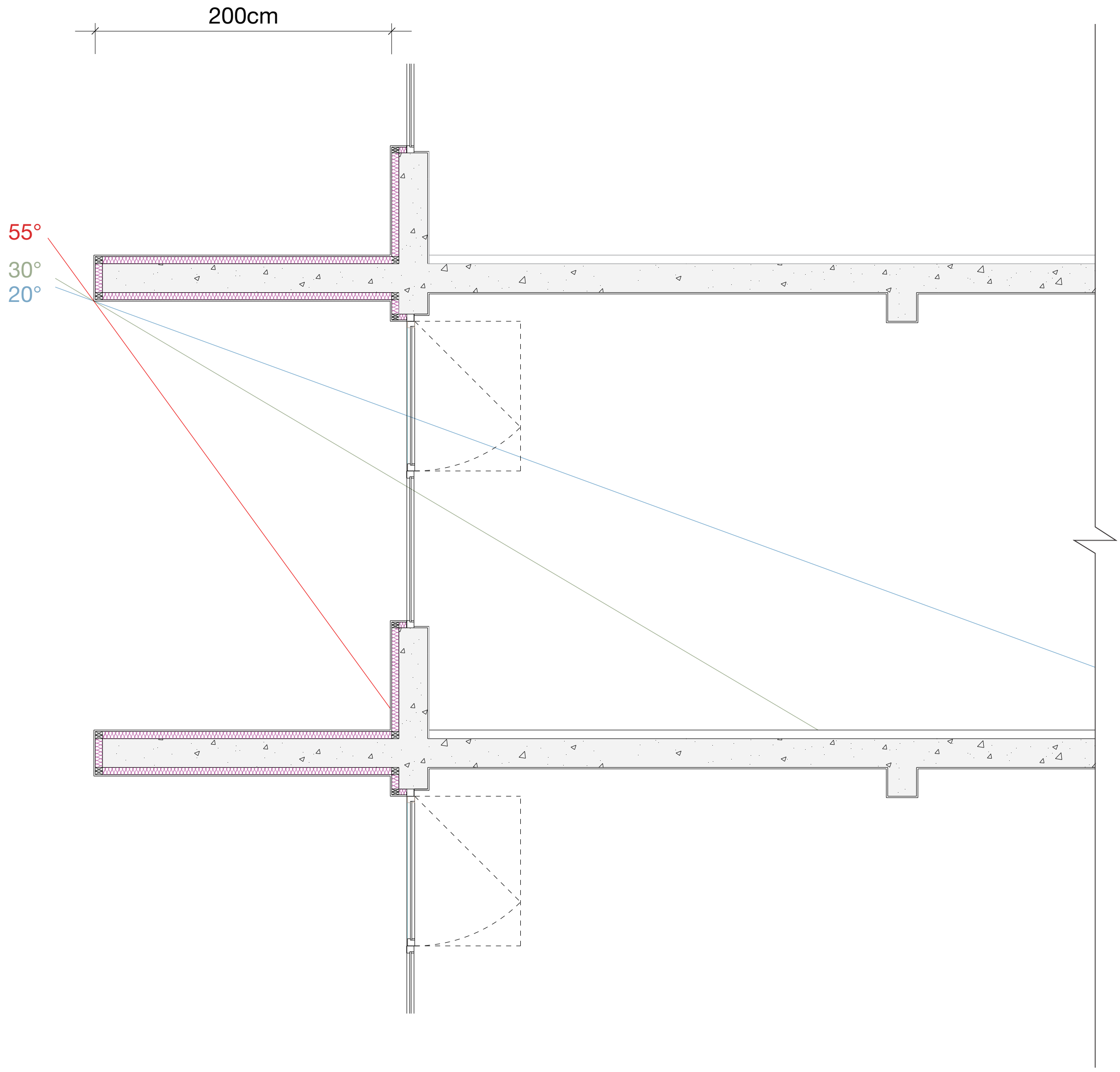


Figure 3.1.45 The shading devices of the existing hotel room in Southeast

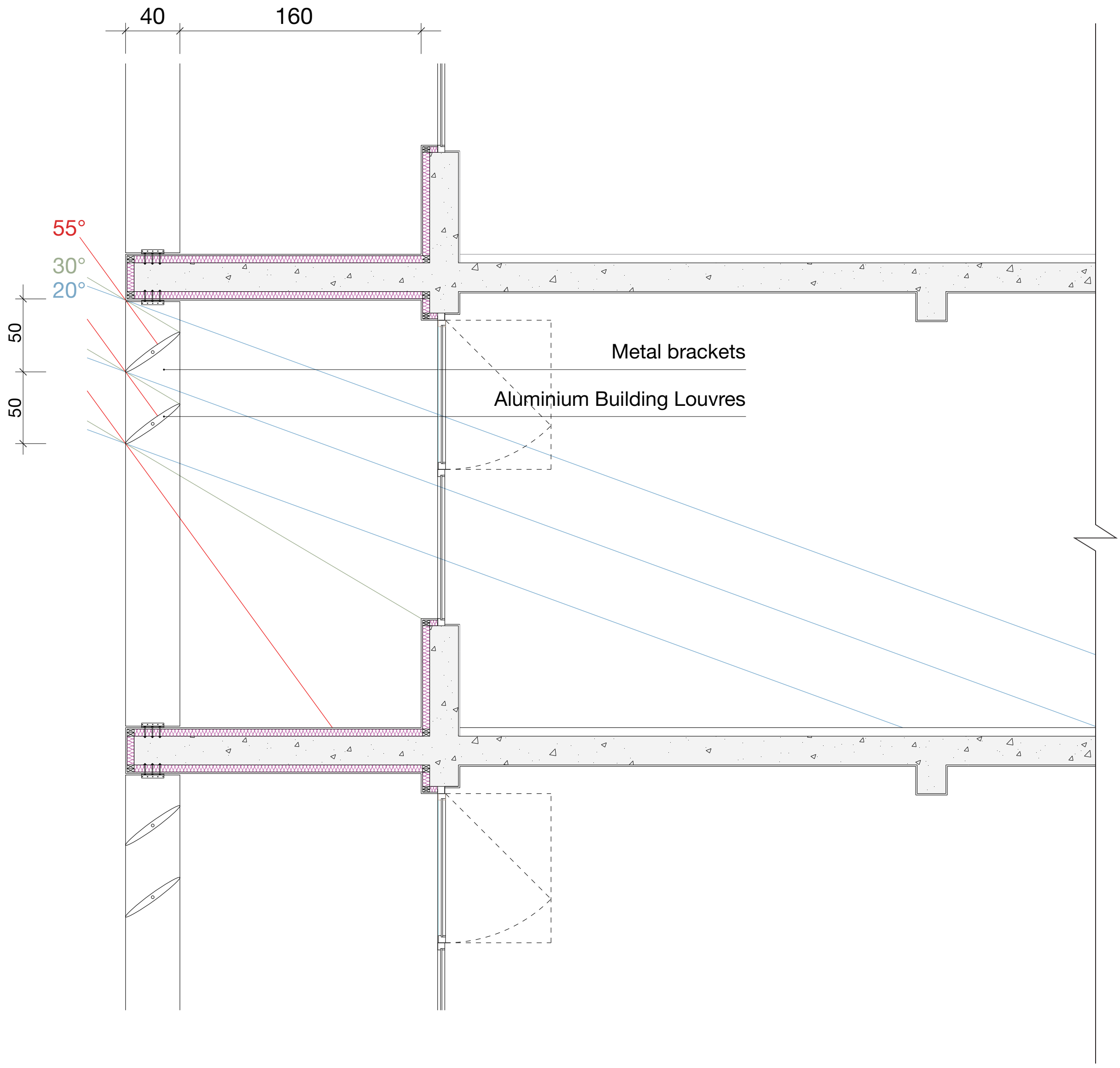
Source: Created by author, 2024

Unit:cm



Solar altitude angle is 55° in summer
Solar altitude angle is 30° in summer
Solar altitude angle is 20° in winter

Figure 3.1.46 The shading devices of the post-retrofitting hotel room in Southeast
Source: Created by author, 2024
Unit:cm



For the hotel rooms located in the southeast, there is a 200cm long fixed overhangs to block part of the sunlight. According to the shading mask, we can see that it can effectively block the direct sunlight at noon in summer; but for the Lingnan region, the direct sunlight in spring and autumn is still very strong. Therefore, **adjustable louvers were added on the basis of the existing fixed shading devices** to better block the sunlight in spring and autumn, and let the winter sunlight enter the room.

Conclusion

Why Choose High-Rise Buildings as the Research Topic?

As China's urbanization increased in the early 21st century, numerous high-rise buildings were built. Height limits on buildings have been overcome by technology. However, global warming and energy restrictions have highlighted high-rise buildings' environmental implications.

High-rise buildings use a lot of steel and concrete, polluting the environment. Although timber skyscrapers have emerged, their foundations are mostly steel and concrete. HVAC systems are essential to high-rise structures, resulting in massive operating carbon emissions. Consequently, in addition to investigating the construction of taller structure, enhancing the sustainability of high-rise structures and mitigating carbon emissions has emerged as a critical concern for China in the future decades.

The Lingnan region, which has the highest amount of high-rise buildings in the world, is the study subject in the thesis. Some of the earliest high-rise buildings in this area have been in use for over 50 years and it is the time need to be retrofitting. Additionally, urban renewal has rendered many old high-rise buildings obsolete, with some even left vacant. Consequently, retrofitting these buildings, including upgrading their functions and envelopes to meet modern societal needs to reduce the need for new construction and lowering carbon emissions, presents a significant challenge.

Why Review Local Traditional Dwellings?

In the second chapter of this paper, two typologies of traditional dwellings were reviewed: courtyard houses and bamboo houses. These case studies analyze how such buildings achieved heat prevention, natural ventilation, and shading to enhance comfort without air conditioning. Although these are low-rise structures, they provide inspiration that can be applied to the retrofitting of high-rise buildings. **Traditional dwellings are better matched with seasonal wind directions than high-rises builidngs. Most openings face southeast, and cool alleys and patios create complete airflow pathways for natural wentilation. Modern high-rise buildings are mostly tower-style designs. To save costs, elevators and cores are placed in the center, but this layout interferes with natural natural ventilation.**

Traditional dwelling not only use windows as vents, but also door openings as the main vents to improve the natural ventilation. And in traditional dewelling, segmented windows (high-level and low level windows) were used frequenctly that allow people to control ventilation in different ways, unlike modern buildings always with floor-to-ceiling glass windows which just could be open or closed. And Interior partition walls in trandition dewelling rarely reach the ceiling, allowing high-level ventilation and decreasing indoor heat accumulation.

Inspiration form a Retrofit Case Study

In the third chapter, I converted a 56-year-old high-rise hotel into a residential apartment. **The layout of the apartments was optimaized to improve cross ventilation and stack ventilation by using increased wind speeds of the high-rise building.** These adjustments increased airflow within the building and reduced HVAC use, which helped the retrofit maintain indoor thermal comfort for over 90% of the year without air conditioning.

To adopt to Lingnan's hot and humid climate, where summer humidity often exceeds more tham 80%, there are some actions to be uesd:
1.Insulation adding: Adding a 5cm insulation layer to the exterior walls to reduce cooling loads in summer.
2.Glazing type selsction: Low g-value glazing were chosen to effectively block solar heat gain. It

because the weather in Lingnan region in summer is often cloudy, where diffuse radiation is more stronger than direct radiation. And diffuse radiation comes from various angles, this choice provided an efficient way to prevent heat from entering the room.

3. Shading device selection:

• On the southeast facade (windward) of the apartment, The complex shading was avoided to ensure smooth airflow into naturally ventilated areas.

• On the northwest facade of the apartment, shading devices were combined with air-conditioning unit brackets to improve the façade's aesthetic appeal.

• In the hotel part, which rely entirely on HVAC systems, movable shading devices was designed to minimize energy use for cooling, and prevent glare in the room.

Final Insights

This study focus on the potential for retrofitting older high-rise buildings in Lingnan region to adopt to the local environmental:

1. **Adjusting building layouts and opening position**s can greatly improve natural ventilation, reducing the need for energy-intensive mechanical systems.

2. **Upgrading building envelope** can lower energy consumption of the loading load while enhancing indoor comfort.

3. **Retrofitting existing structures to meet the new new social needs is a sustainable alternative to constructing new buildings**, helping to reduce carbon emissions in the urban environment.

By drawing inspiration from traditional Lingnan dwellings and applying practical retrofitting techniques, this thesis offers a way to greener high-rise living and supports the goal of creating low-carbon cities. **However, the scope of application of this study is limited. It is only applicable to areas which have the similar climate characteristics to the Lingnan region and it is the risk to directly applied to other areas with completely different climate conditions.** For example, in Turin, Italy, the climate characteristics are totally different to those in the Lingnan region. Excessive improvement of natural ventilation may increase the heating loads generated during the building operation period. Therefore, it is recommended that in actual application, the local climate conditions and environmental characteristics must be analyzed first to ensure the applicability and effectiveness of the solution.

Acknowledgements

When this report was finished, I thought back on my trip. I owe a great deal to the several people who supported me academically and emotionally during this amazing and challenging event.

Please let me sincerely thank you to my parents. Your continuous emotional and financial support established my academic path. You gave me strength and cheered me. I appreciate you telling me to keep on and dedicate myself; you are my rock.

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Throughout this road, I am appreciative of the emotional support and company my friends provide.You helped me overcome obstacles and stayed motivated through late nights of studying, insightful chats, and listening. I am grateful for your friendship.

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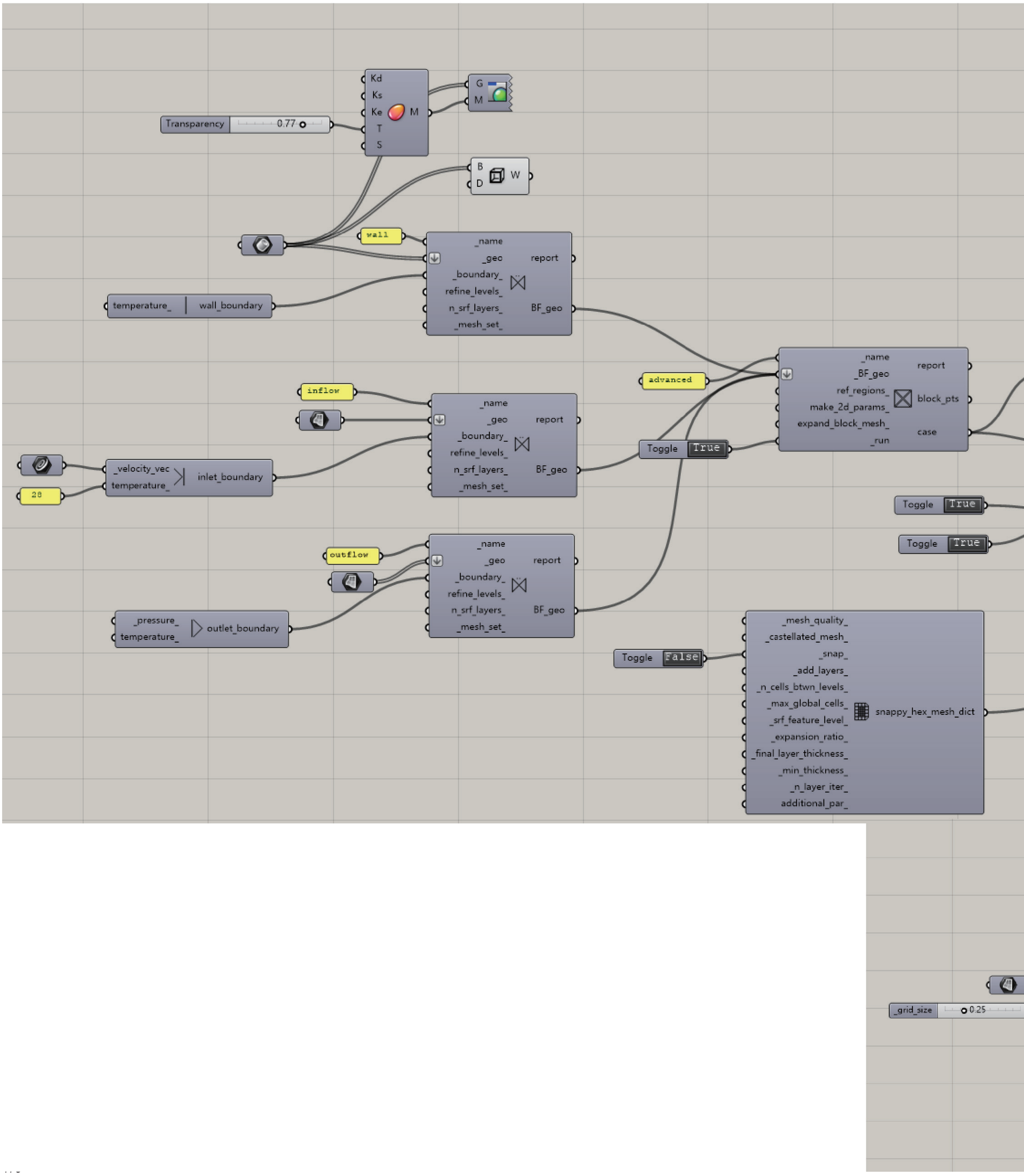
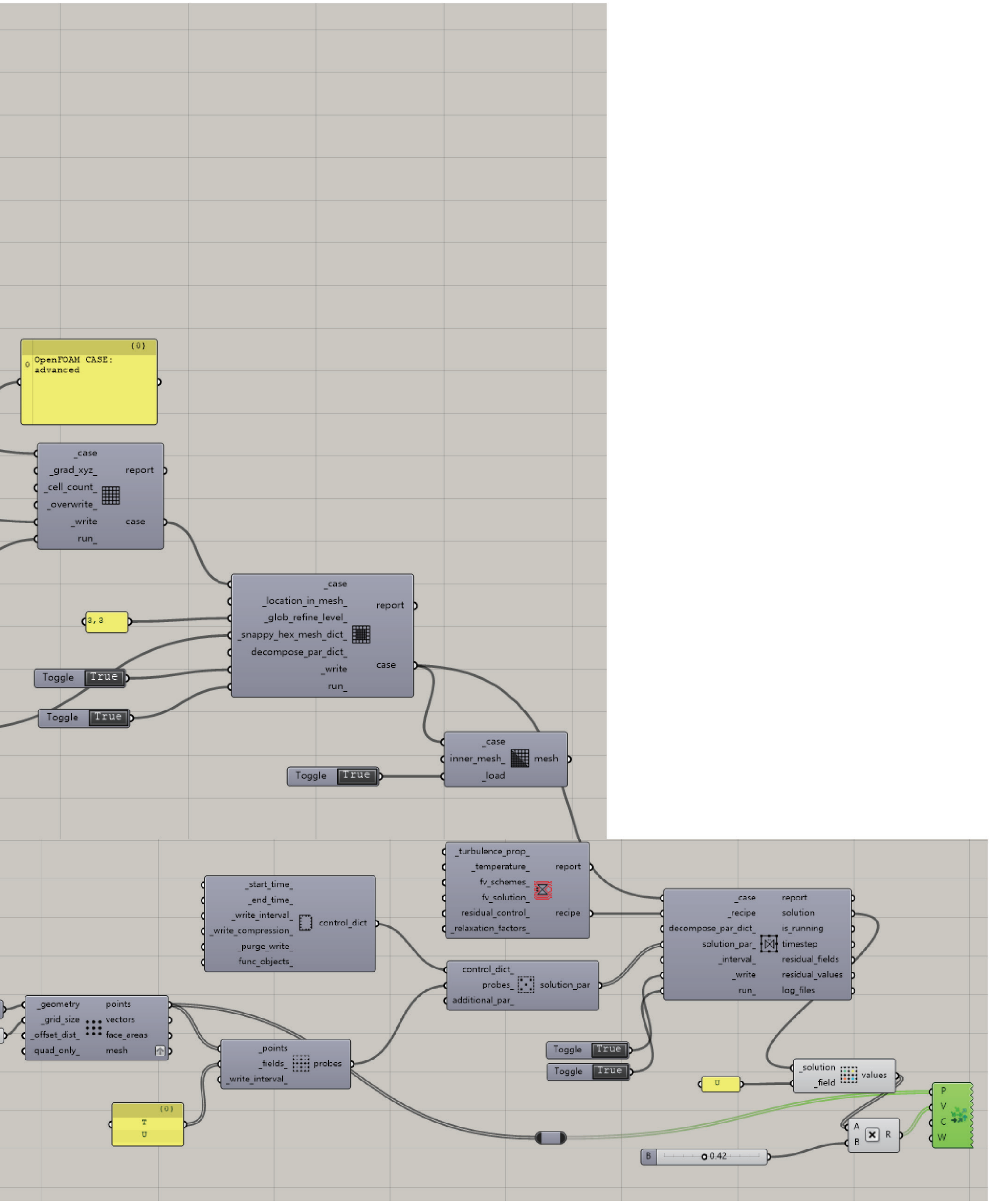
Annex

Figure 4.1 Airflow simulation process in grashopper

Source: Created by author

Software: Butterfly, Grashopper

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_snappy_hex_mesh_dict_
decompose_par_dict_
_write
run_
report
case
Toggle True
Toggle True
_case
inner_mesh_
_load
mesh
Toggle True
_turbulence_prop_
temperature
fv_schemes_
fv_solution_
residual_control_
_relaxation_factors_
report
recipe
_start_time_
_end_time_
_write_interval_
_write_compression_
_purge_write_
func_objects_
control_dict
_case
_recipe
decompose_par_dict_
solution_par_
interval
_write
run_
report
solution
is_running
timestep
residual_fields
residual_values
log_files
control_dict_
probes_
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solution_par
_geometry
_grid_size
_offset_dist_
quad_only_
points
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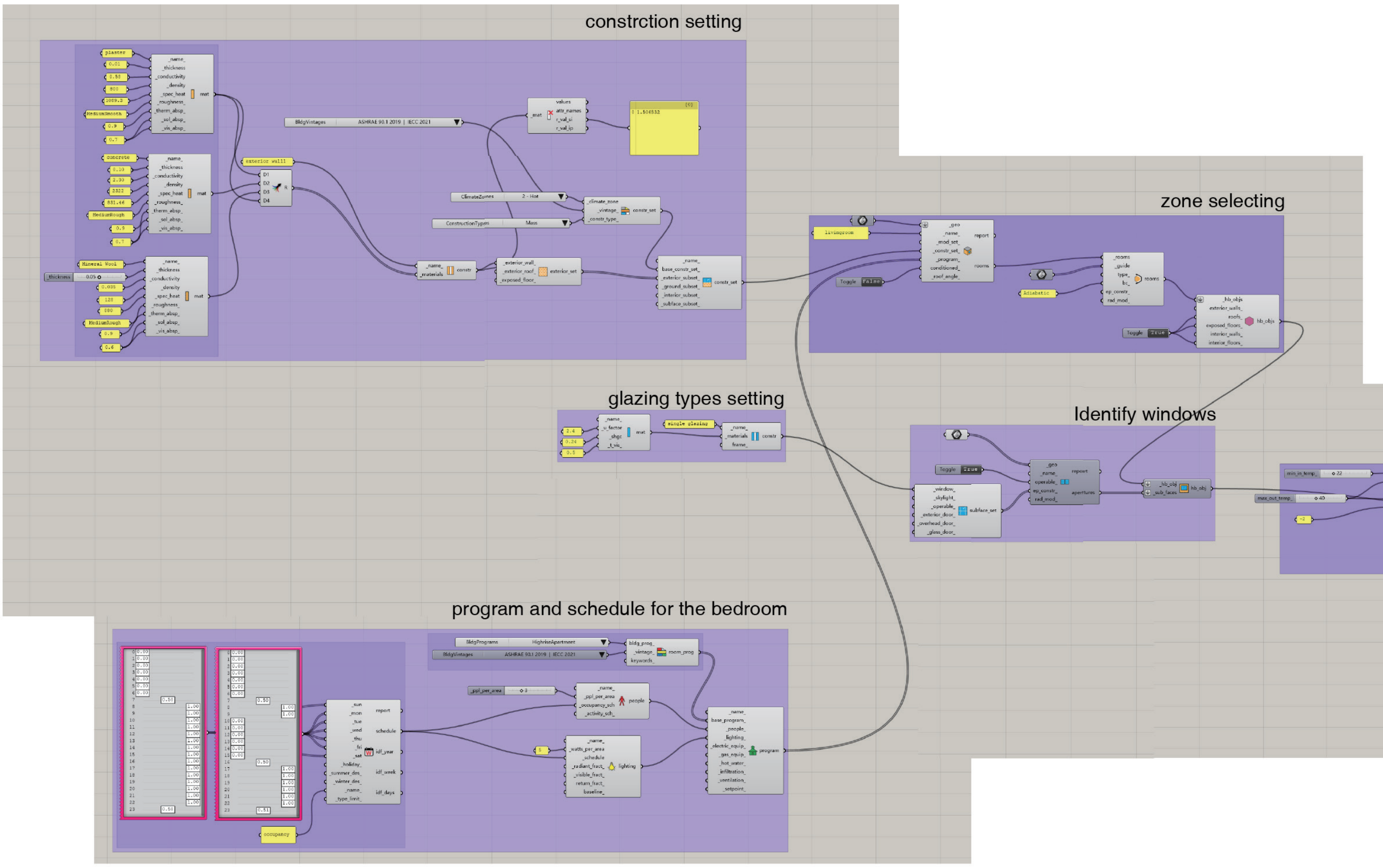
Figure 4.2 Indoor thermal comfort analysis process

Source: Created by author, 2024

Software:Honeybee, Ladybug, Grashopper



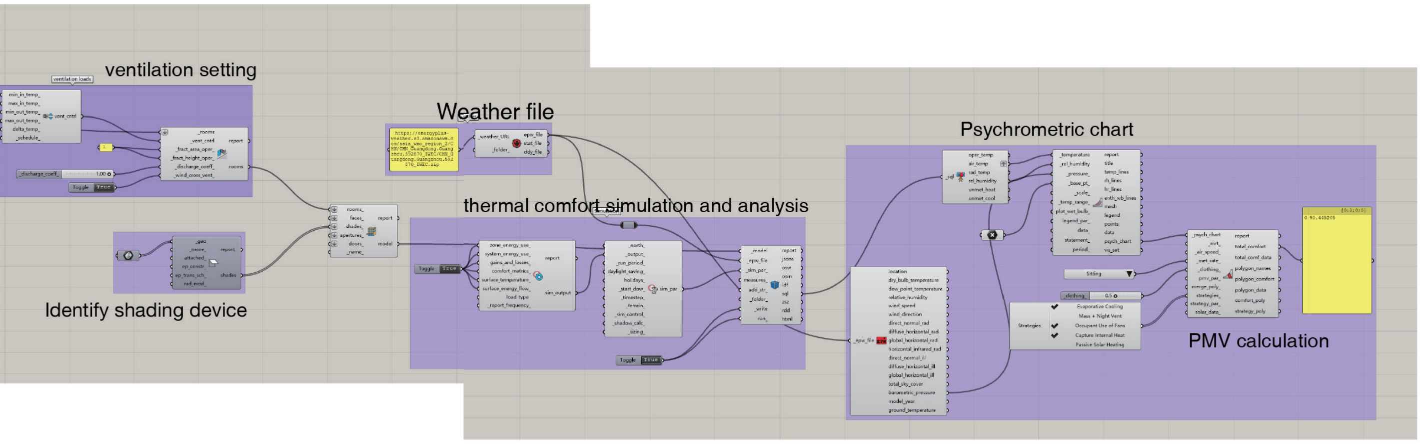
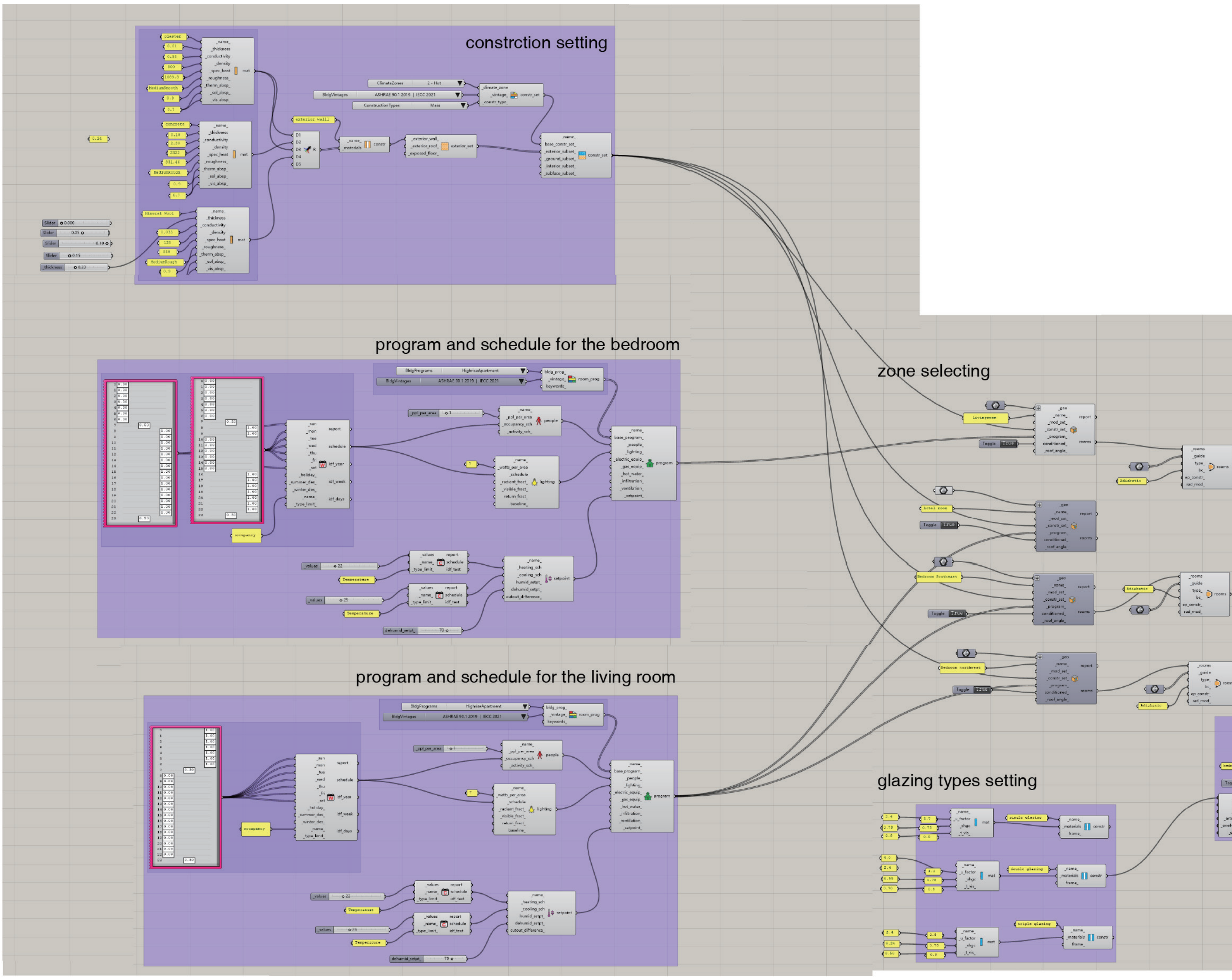
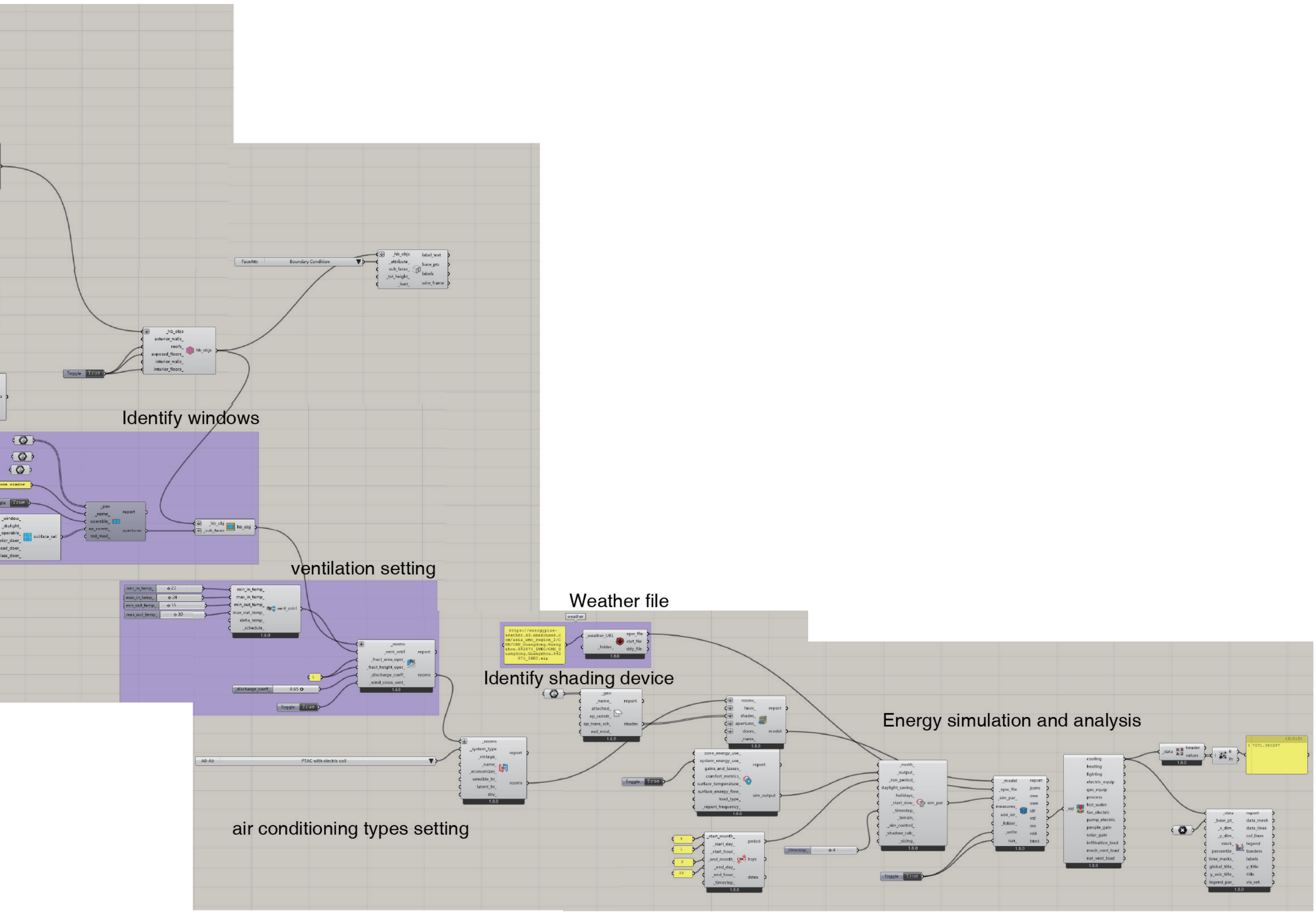

ventilation setting
Weather file
Psychrometric chart
thermal comfort simulation and analysis
Identify shading device
PMV calculation

Figure 4.3 Anual cooling load calculation process

Source: Created by author, 2024

Software:Honeybee, Grasshopper




Identify windows
ventilation setting
Weather file
Identify shading device
Energy simulation and analysis
air conditioning types setting