A Study on Spatial Renovation and Design of High-Density Urban Villages Oriented by Light Health: A Case Study of Guangzhou Shipai Village

A Dissertation Submitted for the Degree of Master

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Abstract

As a crucial component of healthy building design, the light environment has emerged as a significant research topic. Numerous scholars have identified the mechanisms through which lighting conditions affect human health. Within the framework of the "Healthy China" initiative, spatial environments are increasingly expected to support residents' healthy behaviors and lifestyles. Urban villages, characterized by high-density building layouts, often exhibit pronounced light-environment deficiencies. While many regeneration projects adhere to conventional light environment standards, they frequently overlook Light Health criteria. Therefore, this study takes Shipai Village in Guangzhou as a case study to explore Light Health-oriented regeneration strategies for urban villages. In line with the 14th Five-Year Plan's emphasis on stock revitalization, this study adopts a "micro-regeneration" approach that minimizes alterations to the existing urban fabric, such as street layouts and building footprints. It seeks to identify viable Light Health-oriented regeneration pathways under the principle of "under the principle of minimal demolition." The specific research process and outcomes are as follows:

First, Light Health-related theories were systematically reviewed. By integrating domestic and international healthy building standards with exemplary light-environment retrofit cases, light environment indicators were translated into Light Health metrics—complete with definitions and thresholds—to establish a theoretical basis for subsequent strategies. Second, field surveys were conducted to assess the current conditions in Shipai Village. The village is dominated by overcrowded buildings and narrow alleyways, where widespread issues such as inadequate illuminance and poor uniformity persist. Interviews with residents revealed that insufficient lighting negatively impacts daily life, contributing to both physical and psychological health concerns.

On this basis, simulation-based optimizations were carried out for spaces with typical Light Health challenges: at the street level, through the integration of light-guiding devices and high-reflectivity materials to enhance ground-level illuminance; at the building scale, via the insertion of "light wells" and the optimization of window glazing to improve daylight penetration in deep-plan spaces; and at the cluster level, where passive retrofits proved insufficient, through the evaluation of selective demolition strategies to identify the most effective approach for improving daylight efficiency and expanding activity spaces supporting visual health.

Finally, these multi-level regeneration strategies were applied to specific sites in Shipai Village. Their effectiveness was validated by comparing pre- and post-intervention Light Health indicators and spatial configurations, demonstrating that the renovations not only improved measurable Light Health metrics but also encouraged residents to adopt light-healthy lifestyles. By incorporating the "property-right exchange" model used in Liede Village, an implementation pathway was proposed to address complex ownership structures and low resident participation willingness, thereby enhancing the feasibility of real-world application.

This study represents an initial exploration of Light Health-oriented regeneration approaches for high-density urban villages in Guangdong. It proposes and validates a set of contextualized Light Health renewal strategies for Shipai Village, offering a transferable methodology for other similar communities. The research holds both theoretical and practical significance for advancing healthy regeneration in high-density urban contexts across China.

Keywords: Light Health; High Density; Urban village renewal; Light environment optimization; Shipai Village, Guangzhou

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Chapter1. Introduction

1.1. Research Background

1.1.1. Healthy China

Since the 20th century, the rapid advancement of industrialization and urbanization has significantly enhanced the efficiency of urban living and working environments, while simultaneously giving rise to a series of social, sanitary, and ecological challenges. Among these, the issue of human residential health has increasingly become a focal concern on a global scale. In 1984, the World Health Organization (WHO) first introduced the concept of the "Healthy City" and launched the Healthy Cities Project (HCP) in 1986[1][2]. The study of "habitat and health" has since attracted worldwide attention, and health has emerged as a critical theme in architecture and sustainable development.

In 2017, the "Healthy China" strategy was proposed at the 19th National Congress of the Communist Party of China. Through policy documents such as the "Healthy China 2030" Planning Outline [3], health-oriented development was incorporated into the objectives and implementation framework of urban construction, thereby advancing more actionable strategies for improving the quality of the urban and residential environment. Around 2010, domestic research began to emphasize the relationship between urban regeneration and healthy community building. Following the release of the Healthy China 2030 Outline in 2016, health-oriented community renewal has increasingly prioritized human health as a primary consideration in planning and design. By optimizing the physical spatial environment—including access to daylight, natural ventilation, greenery, and the quality of public space[4]—such approaches aim to foster healthy behaviors and lifestyles. Against this backdrop, health-focused interventions within urban regeneration are positioned as a key pathway to implementing "Healthy China," and should therefore receive sustained attention and advancement within planning, design, and evaluation systems.

1.1.2. Light Health

"Light Health" is a core concept that has recently emerged through interdisciplinary research across architecture, medicine, and environmental psychology. Light Health exerts multifaceted impacts on human well-being through visual, non-visual, and psychological dimensions[7]. With the advancement of technology and evolving societal needs, the scope of light's role has extended beyond traditional "visual functions" to encompass "physiological regulation," "emotional modulation," and "cognitive enhancement" [8][9], as illustrated in Figure1- 1.

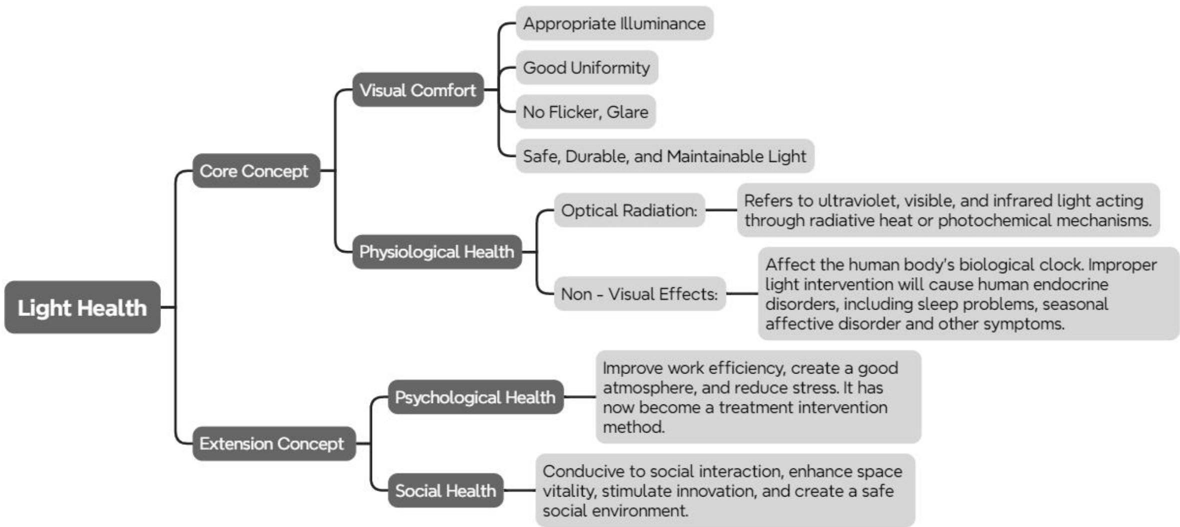


Figure1- 1Conceptual of Light Health

Source: Author

A substantial body of domestic and international research demonstrates that the built environment exerts multidimensional impacts on residents' physical and mental health. Among these factors, the light environment is closely associated with both psychological comfort and physiological well-being, as illustrated in Figure1- 2. Excessive building density, insufficient openness of public spaces, and poor environmental hygiene are strongly correlated with residents' psychological distress and impaired bodily functions.

In high-density communities such as urban villages, residents are often exposed to inadequate daylighting conditions due to compact building layouts, limited solar access, low degrees of spatial openness, and a lack of greenery. These deficiencies may negatively influence visual comfort, physiological health, quality of life, emotional regulation, and circadian rhythm. Current urban village regeneration policies predominantly focus on issues of land tenure and morphological transformation, while paying insufficient attention to the potential health implications of fundamental environmental factors such as the light environment. For instance, in cases such as Liede Village and Shipai Village, even after the renewal of public spaces, residents may continue to experience low levels of comfort and environmental health[10].

Therefore, incorporating Light Health as a critical dimension in the regeneration of urban villages can exert positive effects on both the physiological and psychological well-being of residents. This approach aligns closely with the objectives of the Healthy China initiative, while also offering new perspectives and strategies for urban village renewal.

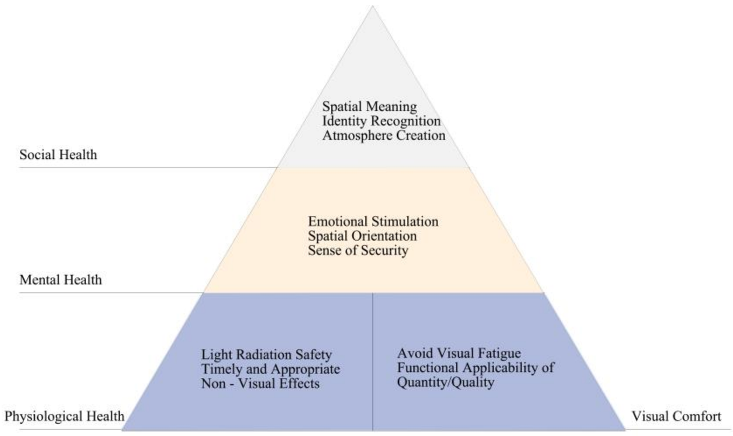


Figure1- 2Maslow Model of Healthy Light Environment Evaluation System

Source: Literature[46]

1.1.3. Light Environment in Urban Villages

With the advancement of the Healthy China strategy and the deepening of discourses on urban health development, the relationship between community environments and public health has attracted increasing attentio n[5]. Urban villages, as a distinctive settlement form that has emerged during the rapid process of urbanization, have long accommodated the housing demands of a large inflow of migrants and low-income groups due to their unique formation mechanisms and governance structures. However, such areas are typically characterized by high density, high floor area ratio, and self-built construction [6], resulting in an extremely compact spatial configuration. Narrow alleyways, highly compressed public and green spaces, and insufficient solar access and ventilation collectively give rise to pronounced light environment problems.

Extensive field investigations and related studies reveal that poor daylighting conditions and problematic light environments within urban villages have become a widespread concern. These settlements are commonly described by the spatial attributes of being “dirty, chaotic, dense, and dark.” They are marked by excessive building density, disordered layouts, narrow internal roads, insufficient public facilities, and limited green space. Dense building spacing and unregulated extensions or additions have created extreme building typologies such as “handshake buildings” and “sky-line corridors” [5], which obstruct the penetration of natural light into living spaces. As a result, the majority of residential units remain in low-illuminance conditions throughout the year. Interior spaces suffer from inadequate daylighting—lower-floor units are particularly dim, with some rooms relying on artificial lighting even during daytime to meet basic living needs. Although rooftops and interstitial open spaces between buildings have potential utilization value, they are often underutilized and remain largely inactive. The prevalence of narrow streets, tall buildings, and compact block patterns further restricts sunlight penetration, generating a sense of spatial oppression among residents. Insufficient daylight not only undermines residential comfort but also suppresses social interactions, leading to passive public spaces and reduced neighborhood communication.

At present, the Healthy China strategy identifies the creation of a healthy and livable residential environment as one of its core objectives, emphasizing the need to enhance residents' well-being from spatial, environmental, and governance perspectives. However, urban villages, as a special spatial typology under rapid urbanization, present a stark contradiction between their existing light environment conditions and the requirements of healthy community building. The persistent lack of adequate daylight in high-density neighborhoods leaves the health needs of a substantial portion of residents unmet. Consequently, improving the quality of the light environment under the spatial constraints of dense urban villages—through the effective introduction and redistribution of natural light—has become one of the key challenges for implementing the healthy community concept and enhancing residents' quality of life and overall health.

1.2. Research Objectives and Significance

1.2.1. Research Objectives

This study focuses on three progressively deepening objectives:

1.To systematically review the theoretical evolution and current state of research on light and health, integrating domestic and international evaluation indicators and influencing mechanisms. Based on this synthesis, the study aims to select and construct a light–health theoretical framework and baseline indicators applicable to high-density built environments, thereby providing a theoretical foundation for light environment optimization.

2.To address practical problems of insufficient natural daylight and heavy reliance on artificial lighting in urban villages, the study proposes Light Health–oriented renewal strategies. These strategies specifically respond to challenges of daylight improvement, visual and non-visual health enhancement, and comfort optimization under high-density conditions, forming actionable spatial and technological interventions.

3.Using Shipai Village, a typical urban village in Guangzhou, as a case study, the research conducts empirical design verification through field investigation, daylight measurement, light environment simulation, and design practice. The aim is to test the applicability and effectiveness of Light Health strategies in real contexts, ultimately generating transferrable and replicable approaches to urban village regeneration. These strategies can provide innovative perspectives for healthy community construction and residential environment renewal in China.

1.2.2. Research Significance

(1) Theoretical Significance

Under the Healthy China strategy, higher requirements have been placed on the health performance of architecture and urban space. As an environmental determinant of both visual and non-visual health, the light environment is still predominantly framed by international studies and high-standard buildings, which show limited adaptability to high-density residential spaces in China. This research, taking Guangdong’s typical urban villages as its case, seeks to extract evaluation indicators and health thresholds suitable for high-density neighborhoods. By clarifying the causal pathways between light environment indicators and human health, it aims to enrich and refine the theoretical system of Light Health in urban village contexts, providing methodological references and indicator support for future diversified studies on healthy living environments.

(2) Practical Significance

As primary housing spaces for large-scale migrant populations and middle- to low-income groups, urban villages are critical to issues of urban equity, social governance, and residents' well-being. This study focuses on insufficient daylighting and its impacts on residents' health, and proposes Light Health–oriented renewal strategies and evaluation frameworks based on micro-renovation. These frameworks can guide urban regeneration projects in achieving daylight optimization and health improvements under limited spatial conditions, facilitating the transformation of urban villages into healthier and more livable communities. Moreover, the results can provide governments, design institutes, and other stakeholders with scientific Light Health design guidelines and practical evaluation tools, helping to enhance overall residential quality in urban villages and similar high-density, aging neighborhoods, while promoting comprehensive improvements in residents' health and well-being.

1.3. Research Object, Methods, and Content

1.3.1. Research Object

This study takes Shipai Village, a typical high-density urban village in Guangzhou, Guangdong Province, as the primary research object. It focuses on the village's spatial morphology and existing light environment, exploring how natural daylight optimization in dense urban contexts can enhance residents' health.

(1) Urban Villages

As a unique urban spatial typology in Guangdong, urban village renewal has long been a key topic in research. Shipai Village, located in Guangzhou's central urban area, represents a typical high-density urban village. With a high proportion of land area and dense population, its spatial morphology is characterized by "handshake buildings." The built fabric is extremely compact, with disordered building arrangements, narrow and enclosed alleyways, and average height-to-width ratios of ≤0.5. The settlement lacks systematic public space, resulting in inadequate solar access and leaving most residents in persistently low-illuminance environments.

(2) Light Health

This study concentrates on the conceptualization and implementation of Light Health in urban village spaces. Light Health influences both physiological and psychological dimensions of human well-being, mediated through natural daylight optimization and artificial lighting enhancement. As the author is a student of urban design, the research emphasis is placed on urban spatial strategies for natural daylighting. Artificial lighting issues—such as fixture typology or lighting engineering—fall beyond the scope of this study. By investigating Light Health from the perspective of spatial design, the study seeks to derive reasonable daylighting strategies that effectively regulate visual comfort and biological rhythms (e.g., circadian rhythm), thereby promoting psychological health and overall living comfort.

1.3.2. Research Methods

(1) Literature Review

By collecting and synthesizing key domestic and international literature on healthy architecture, Light Health theory, healthy communities, and urban village regeneration, this study identifies research gaps, clarifies the interfaces between light environment indicators and health effects, and analyzes how physical spatial interventions guide or promote healthy behaviors. This establishes the theoretical foundation and evaluation indicators for the study.

(2) Field Investigation

Within the research site of Shipai Village, spatial surveys, illuminance measurements, and resident interviews are conducted to collect data. Specifically:

Spatial Mapping: Mapping of typical street sections, building floor plans, and spatial morphology parameters to analyze the relationship between spatial enclosure and daylight performance.

Illuminance Measurement: Using professional lux meters, natural daylighting levels in streets and alleys are measured at different times and representative locations to capture the objective light environment conditions.

(3) Simulation Analysis

Based on field data, daylight simulations are carried out using tools such as Velux, Rhino, and Grasshopper at both urban and building scales. These simulations quantify daylighting performance across spatial scales, verify proposed indicators, and optimize corresponding design strategies.

1.3.3. Research Content

(1) Interfaces between Light Environment Indicators and Light Health Indicators

Building upon a systematic review of existing domestic and international theories and standards on light and health, and considering the spatial characteristics of urban villages alongside residents' needs, this study identifies applicable natural daylighting evaluation indicators. It further clarifies the interface relationships between light environment indicators and human health effects, thereby developing a quantifiable and operational Light Health–oriented evaluation framework.

(2) Investigation and Problem Analysis of the Existing Light Environment in a Typical Urban Village

Through field surveys and on-site measurements, the study captures the daylighting conditions of various spatial types in Shipai Village. By integrating these findings with residents' behavioral patterns, it diagnoses the primary deficiencies of the current light environment and their potential health implications. Representative spatial prototypes are extracted, and specific improvement requirements are formulated for each type.

(3) Research on Light Health–Oriented Regeneration Strategies

Based on the prototypes of typical urban village spaces, and with reference to the characteristics of the district, street–alley morphology, and building conditions, this study proposes indoor and outdoor Light Health optimization strategies, adhering to the principle that partial demolition is considered only as a last resort after all feasible daylighting improvements have been implemented, prioritizing improvements based on existing street fabrics and building structures. The research explores how overall natural daylight conditions can be enhanced in urban village renewal projects, guiding residents to develop Light Health–oriented lifestyles. Prototype-based optimization simulations and strategy verification are employed to assess feasibility, providing methodological references and theoretical support for subsequent practical applications.

1.4. Domestic and International Research Progress

1.4.1. Development of Light and Health Research

The development of light and health research can be divided into five major stages: the early exploration stage from the late 19th to early 20th century, the visual effect research stage from the early to mid-20th century, the non-visual biological effect discovery stage from the mid- to late 20th century, the formation of a comprehensive light–health concept in the early 21st century, and the modern research and application stage from 2010 to the present. The detailed evolution is as follows:

Research on light and health began in the 19th century with Florence's scientific elaboration of the therapeutic value of light [11]. In the 1960s, Wurtman revealed the physiological mechanism by which light regulates melatonin synthesis through animal experiments [12]. The discovery of the retinohypothalamic tract in 1972 [13], followed by Lewy's artificial light experiment in 1980, formally established the existence of non-visual effects in humans [14]. In 2002, Berson and colleagues discovered intrinsically photosensitive retinal ganglion cells (ipRGCs), confirming that blue light at 484 nm represents the peak wavelength for circadian regulation. Lucas further clarified that light activates photoreceptors to trigger a cascade of hormonal secretions, thereby influencing biological rhythms and health markers[15].

Subsequent studies deepened this field: in 2004, Figueiro highlighted the spectral complexity of non-visual effects; in 2007, Chen Zhonglin demonstrated the significant role of short-wavelength spectra in promoting pupillary constriction [16]. After 2010, research shifted toward multi-factor interaction mechanisms: in 2012, the American Medical Association warned that nighttime light exposure could disrupt DNA metabolism and cell cycles[17][18][19];

in 2015, Cajochen verified the dual-pathway effect, where short-wavelength light suppresses melatonin while long-wavelength light enhances alertness [20]; in 2016, Ohayon revealed that outdoor light pollution delays human sleep rhythms[21].

Recent breakthroughs include findings that even weak light below 30 lx can interfere with circadian rhythms[22], prolonged light exposure can elevate cortisol levels and concentration [23], and Hao Luoxi (2017) proposed the "visual–biological–emotional" ternary health model [24]. Current consensus suggests that light environments must integrate both visual and non-visual effects, employing dynamic spectral design to align with human circadian rhythms [25]. Nevertheless, the underlying mechanisms remain to be explored through interdisciplinary collaboration.

In the process of translating theory into practice, different countries and regions have shown divergence in research priorities, technological applications, and standard-setting. Thus, domestic and international studies on light and health present distinct characteristics in terms of scope, core content, and applied practices. Table1- 1 compares the current state of research at home and abroad to better understand both the present development and future trends of light and health research.

Table1- 1Current Status of Light Health Research in China and Abroad

Source: Author

Dimension	Domestic Research Status	International Research Status
Research Coverage	Focuses on conventional scenarios such as education, office, healthcare, and elderly care; few studies in extreme environments. Understanding of healthy lighting is gradually deepening, and non-visual biological effects are beginning to receive attention.	Covers multiple fields, including extreme environments such as polar regions, aerospace, and deep sea; emphasizes exploring the potential applications of light in mental health and emotional regulation.
Core Research Content	Emphasizes visual health (e.g., color rendering index, glare control, illuminance) standards and applications; few studies apply non-visual effects in medical settings. Other non-visual effects such as blue light hazards and dynamic lighting regulation are still in early stages.	Places equal emphasis on visual health and non-visual effects, covering visual functions, circadian rhythm regulation, and emotional interventions. Studies on the combination of natural and artificial lighting and light's effects on the immune system are more

		advanced.
Technology Applications	LED lighting has made progress in intelligent control, but dynamic dimming applications are limited; considerations of healthy lighting are relatively common in green and health-oriented buildings.	Intelligent healthy lighting technologies are mature; dynamic dimming and spectral optimization systems are widely applied in education, healthcare, and other fields. Light therapy technologies are extensively used for treating mood disorders.
Standardization and Policy Support	Domestic standards such as “Evaluation Standard for Healthy Buildings” [7] and “Daylighting and Lighting Hygiene Standards for Primary and Secondary Classrooms” [26] mainly regulate visual health; standards for non-visual effects are still under development.	International organizations such as CIE and WELL have issued systematic healthy lighting standards covering both visual and non-visual effects; standards are also applied in extreme environments, e.g., lighting design guidelines for the International Space Station.
Research Challenges	Lacks interdisciplinary collaboration; theoretical research and technological applications are disconnected. Research on healthy lighting needs in extreme environments and special populations (e.g., elderly) is insufficient.	Personalized healthy lighting design in extreme environments is not yet fully mature; practical applications face cost barriers. Research on healthy lighting for diverse populations (gender, age, regional differences) remains incomplete.

In summary, international research occupies a leading position at the forefront of exploration. It encompasses broader research domains and demonstrates more advanced technological applications, with particular emphasis on the comprehensive health benefits of light—covering psychological, emotional, and physiological dimensions—as well as its application in extreme environments. Nevertheless, limitations remain in terms of practical implementation and the inclusion of diverse population groups.

In contrast, domestic research is in a stage of rapid development. Current efforts are more focused on addressing fundamental needs while actively expanding understanding of non-visual effects, leading to considerable progress. However, gaps persist compared with international standards, particularly in interdisciplinary integration, frontier exploration, and the depth of technological application.

1.4.2. Modes of Urban Village Renewal

In the process of China's urbanization, urban villages have long persisted as a distinct spatial form, with renewal involving complex issues across economic, social, and environmental dimensions. In recent years, practice has shifted significantly from a model of complete demolition and reconstruction toward approaches of comprehensive rehabilitation and incremental micro-renewal[27][28], placing greater emphasis on organic regeneration and gradual advancement [29].

Studies consistently show that the high-density built form of urban villages results in unreasonable building spacing, widespread insufficiency of natural lighting, and poor ventilation[30]. The prevalence of dead corners with inadequate daylight and strong visual obstruction further undermines residents' sense of safety[31]. To address these physical deficiencies, scholars have proposed a range of preservation-oriented and optimization-based strategies: for example, the use of light-guiding panels and reflective boards as low-cost micro-renewal measures to improve indoor light conditions[32]; or treating light and heat as "unhealthy factors" and optimizing vegetation configuration to improve both microclimate and natural daylighting [30].

It is important to note, however, that health benefits cannot be achieved solely through physical interventions. Liu Jiahui's research demonstrates that health outcomes are shaped by the combined influence of the physical and social environment, whereby improvements in the material environment and social capital can indirectly promote both physical and psychological well-being[10]. This confirms the necessity of a dual-level strategy: materially, to enhance daylighting and ventilation through planning and design and thus provide the physical foundation for light-healthy living; and socially, to consciously cultivate community health awareness, stimulating residents' spontaneous healthy behaviors and fostering a sustainable lifestyle.

As a typical representative of high-density urban villages, Guangzhou's Shipai Village reflects common spatial characteristics such as density, narrow alleyways, and functional hybridity[33]. Overall, current renewal research emphasizes micro-scale interventions to maximize improvements in residential health conditions, while also highlighting the role of environmental optimization in guiding public awareness, thereby advancing the inclusive and sustainable development of urban villages.

1.5. Innovation Points

Building on the existing limitations in research on high-density urban village renewal and Light Health, this study explores interventions at two levels: indicator integration and design strategies. The main contributions are summarized as follows:

(1) Optimization of Light Environment Indicators Integrating Standards and the Light Health Concept

Given the limited consideration of health in existing urban village light environment indicators, this study, based on a comprehensive review of domestic and international Light Health theories and related healthy building standards, proposes an integrated set of indicators. Traditional light environment metrics such as daylight hours, illuminance, and uniformity are combined with core Light Health indicators including vertical illuminance, horizontal illuminance, and daylight factor. This integrated framework provides quantifiable evaluation criteria for Light Health–oriented urban village renewal and offers theoretical validation to support subsequent design interventions.

(2)Light Health Optimization Across Urban Village Spatial Typologies

Addressing typical issues such as poor natural daylighting and insufficient visual comfort in both public alley spaces and residential buildings within urban villages, this study proposes diversified design and renovation strategies based on field surveys and measured data. At the outdoor level, the study examines how alley spatial proportions (height-to-width ratio), wall materials, and open nodes along street edges influence natural light penetration. At the indoor level, strategies involve window design, wall materials, and architectural light wells to enhance natural light utilization and overall Light Health within residential units. By comparing key light environment indicators (e.g., illuminance, average illuminance, daylight factor) under different strategies, the study verifies the feasibility and effectiveness of optimizing indoor and outdoor light environments to improve Light Health in urban villages.

1.6. Research Framework

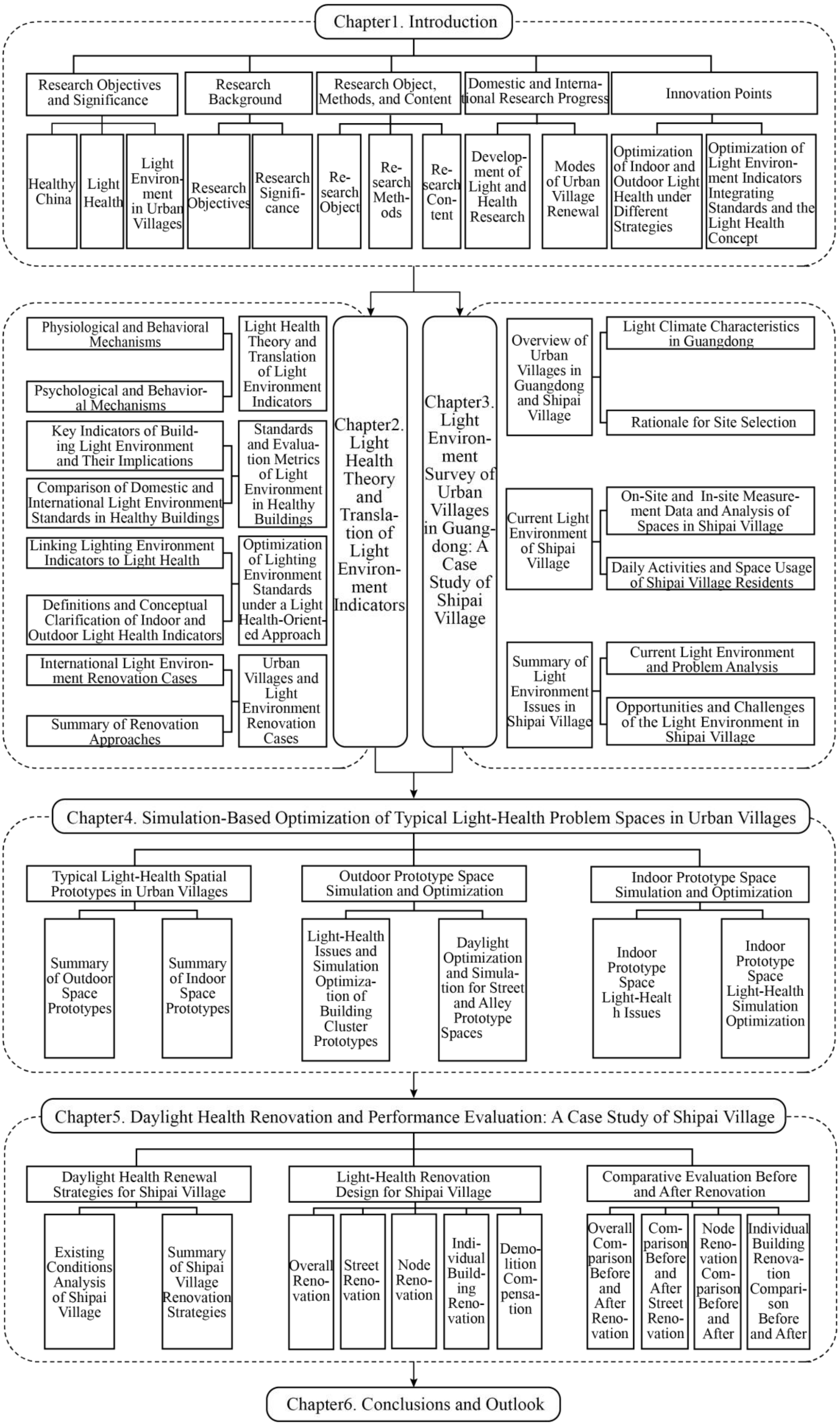


Figure1- 3Research Framework

Source: Author

1.7. Chapter Summary

This chapter systematically reviewed the development and current status of Light Health research and established a research framework for applying Light Health principles to urban village renewal. Starting from the Healthy China initiative and the demand for improving high-density living environments, it identified common issues in urban villages, including insufficient daylight, high reliance on artificial lighting, and poor quality of the light environment, thereby positioning Light Health as a critical entry point for renewal design.

Furthermore, a comparison of domestic and international studies revealed that existing research lacks a systematic investigation of “Light Health indicators” and “Light Health micro-renovation optimization strategies” for urban villages, a typical high-density urban form. As the opening chapter of this study, it clarifies the significance and objectives of the research, providing a foundation upon which the subsequent chapters will build, guided by the research framework outlined herein.

Chapter2. Light Health Theory and Translation of Light Environment Indicators

2.1. Light Health Theory and Translation of Light Environment Indicators

2.1.1. Physiological and Behavioral Mechanisms

Research indicates that mammalian physiological rhythms primarily rely on the retinal photoreceptive system to perceive variations in day–night light exposure. In addition to rods and cones, the retina contains specialized melanopsin-containing photosensitive retinal ganglion cells (mRGCs). According to Haulosi et al., these cells respond to light stimulation by acting on the pineal gland, promoting the secretion of melatonin (MLT), thereby influencing slow-wave sleep and regulating human circadian rhythms[34][35].The effect of light on circadian rhythms is time-dependent: light exposure before midnight can delay the circadian phase, whereas light after midnight can advance it [36]; The magnitude of this effect also varies depending on the timing and duration of exposure [37].Consequently, extreme light environments can significantly disrupt human circadian rhythms, leading to sleep disorders, immune suppression, and other health issues. Circadian disruption is also closely linked to dietary imbalance, while sufficient light exposure can help enhance and stabilize individual food intake [9].

Applications of light environment interventions further validate the profound impact of light on human health. For instance, as shown in Figure2- 1, at the polar Great Wall Research Station, researchers systematically explored how different spectral power distributions (SPDs) affect biological cycles and physiological rhythms by modifying lighting conditions in living quarters, alleviating the adverse effects of extreme natural light conditions on personnel [9].In medical settings such as Intensive Care Units (ICUs), prolonged exposure to artificial lighting can disrupt circadian rhythms in both healthcare staff and patients. Therefore, ICU lighting design must not only meet complex visual task requirements but also protect and regulate the circadian rhythms of both caregivers and patients [9].In eldercare environments, older adults are more sensitive to glare due to visual system degradation, have longer dark adaptation times, and are often further affected by unidirectional daylighting and inconsistent artificial lighting in daily spaces, which can exacerbate discomfort and lead to safety hazards such as dizziness or falls. Thus, health-oriented lighting in senior living spaces needs to prioritize visual comfort and user-friendly design, in addition to fulfilling basic visual requirements[9].

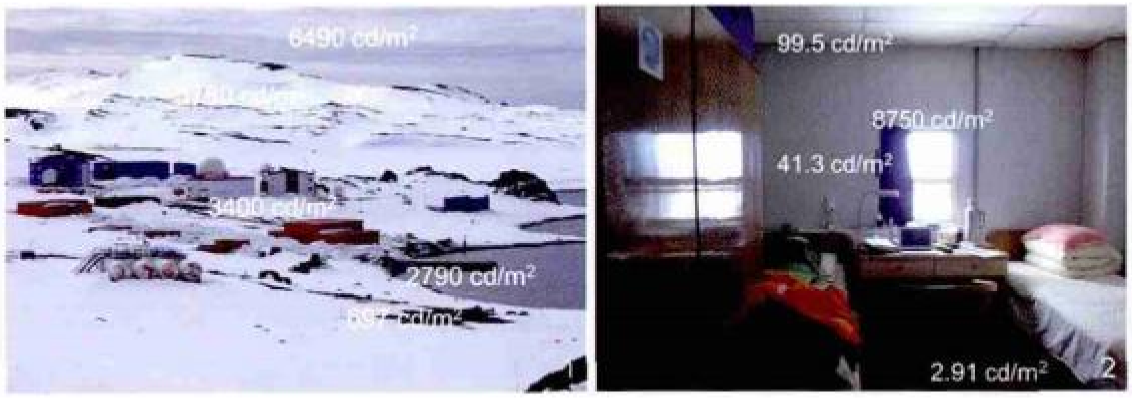


Figure2- 1Current Indoor and Outdoor Luminance at the Great Wall Station in Antarctica

Source: Literature[9]

2.1.2. Psychological and Behavioral Mechanisms

In addition to regulating physiological rhythms via melatonin secretion, light also influences human psychology and emotion. Different lighting conditions can trigger or alleviate tension, anxiety, depression, and other emotional responses, while also enhancing feelings of pleasure and comfort. Multiple studies indicate that, under a fixed color temperature, increasing illuminance within an appropriate range generally enhances positive mood [38]； within certain limits, brighter light tends to correspond to more positive emotional states[39][40].However, when illuminance exceeds a critical threshold, this positive correlation may reverse, potentially producing negative emotional effects [41].High illuminance environments have also been shown to benefit patients with seasonal affective disorder, significantly increasing their vitality[9].Regarding color temperature, research suggests that in regions with distinct seasons, people’s preferences for light color change with seasonal variations [42].

In practical Light Health design, lighting interventions are widely applied to improve users’ psychological well-being. For example, the Chinese Antarctic expedition team at Zhongshan Station employed a “polar LED mood-regulating media interface” that used dynamic colored lighting to mitigate the visual monotony of the polar environment, effectively regulating team members' mood[9].In medical spaces, the cardiac catheterization operating room at Shanghai Tenth People's Hospital implemented lighting modifications that met requirements for glare-free, high-illuminance conditions while introducing adjustable color, pattern, and brightness interfaces for emotional intervention (Figure2- 2). These interventions help patients relieve anxiety and reduce stress for medical staff, enhancing overall work efficiency.In everyday living spaces, a collaborative study by Haulosi's team and OSRAM found that illuminance, light distribution, and color temperature influence subjective perceptions of brightness, warmth, and alertness. Thoughtful lighting design can foster a more comfortable and psychologically healthy living atmosphere. These examples collectively demonstrate that scientific lighting design has a positive impact on emotional regulation and psychological state [9].

Therefore, Light Health interventions are not merely about creating a favorable physical lighting environment; they represent a critical approach to actively modulating users' psychological and emotional well-being through light.

Figure2- 2Interface for Emotional Intervention in Healthcare Spaces

Source: Literature[9]

2.1.3. Promotion of Health by Light Environment in Community Spaces

Modern lifestyles have led to reduced physical activity, limited social interaction, and increased mental stress, all of which negatively impact residents' physical and psychological health. As the primary setting for daily life and social engagement, community spaces play a direct role in shaping health outcomes. By providing opportunities for physical activity, optimizing circulation, increasing green spaces, and improving building layouts, communities can promote exercise, enhance social interaction, and alleviate psychological stress, thereby supporting overall well-being.

Among the various environmental factors influencing health, the light environment—an essential component of the built physical space—directly affects residents' comfort and health through illuminance and daylighting conditions, as illustrated inFigure2- 3[43]. Consequently, the quality of light in community spaces represents a key determinant of health that cannot be overlooked.

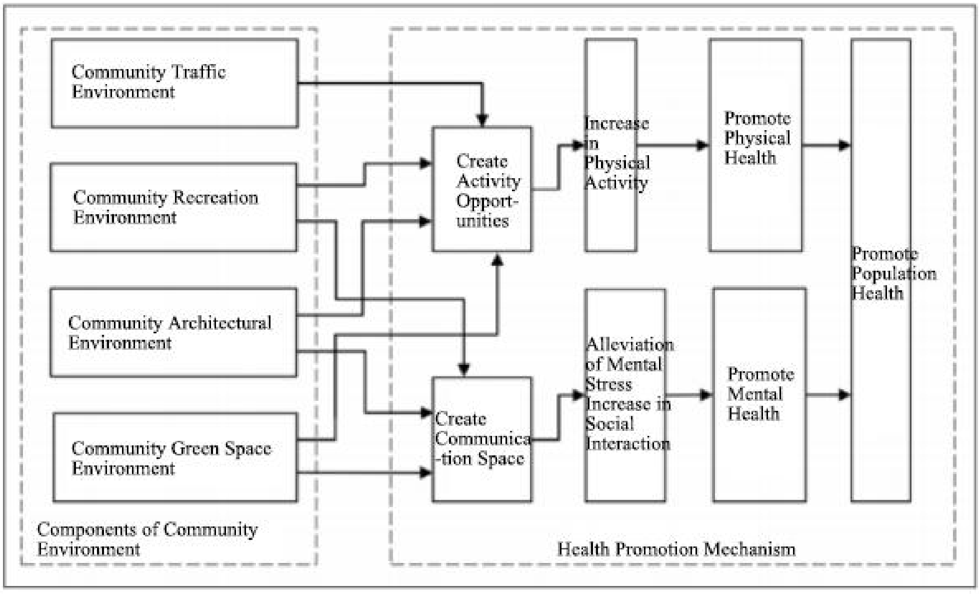


Figure2- 3Community environmental factors and health promotion mechanisms for enhancing population health

Source: Literature[43]

As a distinctive type of community space, urban villages have been shown to significantly influence residents' health through their built environment. Mixed land use, public service facilities, green spaces, and walkable environments contribute to increased physical activity and social interaction, thereby enhancing overall health [4]; Conversely, high building density, insufficient public space, and environmental congestion undermine both physical and psychological well-being. This impact is particularly pronounced in urban villages[5].Within this context, adequate access to natural light not only improves spatial comfort but also stimulates residents' physical activity and social engagement. Enhancing the light environment can thus serve as an important mediating element of the physical environment, promoting the physical and mental health of residents.

2.2. Standards and Evaluation Metrics of Light Environment in Healthy Buildings

2.2.1. Key Indicators of Building Light Environment and Their Implications

Key Indicators of Building Light Environment and Their Implications[44]:

1.Horizontal Illuminance (lux): Reflects the overall brightness of a space; recommended to be ≥300 lx for residential areas.

2.Illuminance Uniformity: Indicates the balance of light distribution; a uniformity coefficient ≥0.5 is considered appropriate.

3.Correlated Color Temperature (CCT): High CCT (>5000 K) appears cool, low CCT (<3300 K) appears warm, suitable for different functional requirements.

4.Color Rendering Index (CRI) and Special Color Rendering: Reflect the light source's ability to reproduce colors accurately; recommended CRI ≥ 80.

5.Glare Value: ≤19 is considered within a comfortable range.

In addition, considering the Light Health dimension, the following metrics are also relevant:

1.Circadian Stimulus (CS): ≥0.3 can achieve effective circadian regulation.

2.Melanopic Equivalent Daylight Illuminance (Melanopic EDI): ≥250 lx is recommended for main daytime spaces.

3.Dynamic CCT Control: The ability to adjust color temperature over time helps synchronize circadian rhythms.

In subsequent research, the author will select core light environment indicators for further analysis.

2.2.2. Comparison of Domestic and International Light Environment Standards in Healthy Buildings

（1）International Standards for Light Environment in Healthy Buildings

With the development of the Light Health concept, relevant international standards and guidelines have been established, as summarized inTable2- 1. Research over the past decade has shown that light affects human biological functions across multiple dimensions. Early studies primarily focused on regulating nocturnal physiological rhythms, examining hormonal variations such as melatonin and cortisol under different lighting conditions. With the deepening of natural light applications, scholarly attention has gradually expanded to include work efficiency, emotional well-being, and social interaction.

Table2- 1Summary of International Healthy Building Light Environment Standards

Source: Author

Standard Name	Country / Year	Relevant Content
BREEAM (Building Research Establishment Environmental Assessment Method) [45]	UK / 2016	Sets requirements regarding light pollution control, visual comfort (including glare control, indoor/outdoor illuminance, and controllability), and related aspects.
LEED (Leadership in Energy and Environmental Design)	USA / 2014	Builds upon BREEAM standards, specifying regulations on light pollution, indoor lighting, natural daylighting, and energy efficiency.
CASBEE (Comprehensive Assessment System for Built Environment Efficiency)	Japan / 2014	Evaluates lighting from a sustainable development perspective, including light pollution, daylight factor, daylight control, illuminance levels, and controllable lighting.
DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen e.V.)	Germany / 2007	Second-generation green building assessment system; includes requirements for natural daylight provision, glare prevention, and color rendering.
JIS Z9110:2010 “Recommended General Rules for Illuminance” /	Japan / 2010	Details lighting environment, illuminance, glare, light color, color rendering, maintenance, and energy saving; provides specific standards for different rooms and

"General Rules for Lighting Standards"		activity areas, including illuminance level, illuminance uniformity, color rendering, and glare rating.
Report on the Development of the Swedish Healthy Home	Sweden / 2014	Specifies elements required for a healthy residential light environment, including visual comfort, aesthetic quality, circadian rhythm regulation, universal design, safety, and optimized energy use; proposes diverse lighting interventions to provide appropriate light at the right time and place for different housing types and occupants.
THE WELL BUILDING STANDARD	USA / 2014	While LEED focuses on building performance, WELL emphasizes the human experience in buildings; specifies visual lighting design, circadian lighting, glare control, daylight exposure, color quality, biological rhythm lighting, dawn simulation, and safe nighttime lighting.
CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light	International Commission on Illumination / 2018	Introduces a measurement system for human non-visual responses to light (e.g., circadian effects), evaluating photobiological effects related to intrinsically photosensitive retinal ganglion cells (ipRGCs).
Research Roadmap for Healthful Interior Lighting Applications	International Commission on Illumination / 2016	Explores research pathways for indoor lighting's effects on human health, including both visual and non-visual responses.
WELL Building Standard v2	IWBI / 2020	Focuses on light environment and human health; includes support for circadian lighting design, enhancement of visual comfort, glare control, and light pollution management.

(2) Domestic Standards for Healthy Building Lighting

In China, research on healthy lighting has primarily focused on theoretical exploration. However, with the development of the industry and increased interdisciplinary exchange, related research content has gradually become more comprehensive. As shown in Table2- 2, the integration and supplementation of existing codes, along with the consolidation and sharing of findings from related fields, are essential for translating research outcomes into practical architectural applications to meet the lighting health needs of diverse environments and populations. With the continuous expansion of healthy lighting theory and its practical applications, China has successively issued multiple policies and standards, such as the Architectural Lighting Design Standard, Building Daylighting Design Standard, and Green Building Evaluation Standard. These regulations provide systematic requirements covering illuminance levels, natural lighting, energy-saving controls, daylight duration, and lighting conditions in public spaces, collectively promoting the ongoing development of the healthy building lighting research framework.

Table2- 2Summary of Domestic Healthy Building Light Environment Standards

Source: Author

Standard Name	Country/Year	Relevant Content
Architectural Lighting Design Standard (GB 50034—2013)	China / 2013	Provides detailed requirements for various lighting environments, including lighting quantity and quality, standard illuminance values, energy-saving measures, and lighting distribution and control.
Residential Health Performance Evaluation Standard	China / 2016	Specifies a residential lighting environment indicator system from the perspective of health performance, focusing on “natural daylighting” and “appropriate illuminance.”
Urban Residential Area Planning and Design Code (GBJ50180–93)	China / 1993	Defines relevant indicators for residential daylighting.
Building Daylighting Design Standard (GB50033-2013)	China / 2013	Proposes that the daylight factor at a 0.75 m reference plane and indoor natural illuminance should serve as the primary evaluation criteria for daylighting design.
Green Building Evaluation Standard (GBT50378-2019)	China / 2019	Further supplements requirements for the proportion of indoor functional spaces making full use of natural light and the duration of daylighting.
Technical Standard for Residential Performance Assessment (GBT50362-2005)	China / 2005	Specifies regulations for daylighting and visual access.
General Code for	China / 2021	Covers daylighting design as well as indoor and

Building Environment (GB 55016-2021)		outdoor lighting design.
Healthy Residential Evaluation Standard (CECS462-2017)	China / 2017	Develops evaluation of indoor natural daylighting into six control and scoring items: sunlight exposure, solar glare control, daylight factor, glare protection, deep-space daylighting, and public space daylighting.

2.2.3. Gaps between Existing Lighting Environment Indicators and Light Health

From a physiological perspective, existing lighting environment indicators—such as horizontal illuminance, illuminance uniformity, color rendering index, glare value, and correlated color temperature—primarily focus on visual brightness and comfort. However, they are insufficient to ensure proper regulation of human circadian rhythms or melatonin secretion. Achieving Light Health requires optimizing these traditional indicators in accordance with circadian requirements in healthy building standards, thereby effectively promoting both physiological and psychological well-being.

From a psychological perspective, while current lighting indicators can satisfy visual comfort, they cannot quantify or directly intervene in emotional or mental states. To meet Light Health objectives, it is necessary to integrate design requirements for psychological comfort and emotional regulation in healthy buildings. By adjusting illuminance, uniformity, color temperature, and dynamic lighting conditions, the lighting environment can positively influence stress, anxiety, depression, and other psychological states, fostering comfortable and enjoyable living and working spaces.

2.3. Optimization of Lighting Environment Standards under a Light Health-Oriented Approach

2.3.1. Linking Lighting Environment Indicators to Light Health

Analysis of existing lighting environment indicators shows that conventional building lighting metrics primarily focus on illuminance, uniformity, and color rendering. Although these metrics meet basic visual requirements, they do not comprehensively ensure proper human circadian rhythm regulation or psychological well-being, nor do they effectively promote Light Health-related living habits. To achieve Light Health objectives, these indicators need to be optimized based on healthy building principles, considering circadian rhythm, emotional comfort, and behavioral safety. Key metrics such as illuminance, daylight factor, color temperature, and lighting schedules should be refined to quantify the lighting environment's positive impact on human physiological and psychological health.

Based on this, the following tables (Table2- 3 and Table2- 4) summarize indoor and outdoor issues affecting Light Health and the corresponding lighting environment indicators. They specify the relevant regulation metrics, adjustment methods, and whether interventions are based on natural daylight or artificial lighting, providing standardized guidance for Light Health-oriented design.

Table2- 3Correlation between Outdoor Light Environment Indicators and Light Health Indicators

Source: Author

Light Health Issue	Adjustment Metric	Adjustment Strategy	Corresponding Lighting Indicator	Daylight / Artificial Lighting
Visual Comfort	Illuminance Uniformity	Control vegetation density and building spacing; optimize ground reflective materials to achieve uniformity ≥ 0.4 [47][48]	Illuminance Uniformity	Artificial Lighting
	Spectral Characteristics	Use low-blue-light LED sources (BPR ≤ 1.2) to reduce retinal photochemical damage [49][50]	Blue Light Control	Artificial Lighting
Activity Limitation & Safety	Illuminance	Use light-colored facade materials to enhance reflection[49]	Illuminance	Daylight
	Safety Lighting	Add pathway/stair lighting facilities[50]	Illuminance	Artificial Lighting
Circadian Rhythm Disruption & Low Mood	Duration of Natural Light Exposure	Arrange open activity areas; minimize building/tree shading to ensure ≥ 2 hours of illuminance > 1000 lx on winter solstice[4][51]	Daylight Duration	Daylight
	Circadian Stimulus (CS)	Simulate daylight spectrum with morning artificial lighting (CS ≥ 0.3) [49][52]	Horizontal Illuminance at Eye Level	Artificial Lighting

Table2- 4Correlation between Indoor Light Environment Indicators and Light Health Indicators

Source: Author

Light Health Issue	Adjustment Metric	Adjustment Strategy	Corresponding Lighting Indicator	Daylight / Artificial Lighting
Visual Impairment	Horizontal Illuminance (lx)	Specify functional zones: Reading/Writing ≥ 500 lx, Elderly Areas ≥ 600 lx [50][52]	Illuminance	Daylight
	Glare Control	Use indirect lighting / anti-glare fixtures to ensure UGR ≤ 19 [49][53]	UGR	Artificial Lighting
	Color Rendering	Ensure indoor fixtures Ra > 90, Rf > 85, approaching natural light color rendering [54]	Color Rendering Index	Artificial Lighting
Circadian Rhythm Disruption	Daylight Factor (DF)	Expand daylight openings + high-reflectance interior walls (DF ≥ 2.5%)[55][56]	Daylight Factor (DF)	Daylight
	Illuminance Timing	Expose to cold white light ≥ 1000 lx for ≥ 30 min in the morning [52]	Daytime Illuminance Duration	Daylight
	Circadian Stimulus (CS)	Morning vertical illuminance ≥ 100 lx (CS ≥ 0.3) [49]	Illuminance at Eye Level	Daylight
Low Mood	Illuminance Uniformity	Use PWM dimming technology (Uo ≥ 0.7) [57]	Illuminance Uniformity	Artificial Lighting
	Dynamic Color Temperature	Adjust color temperature throughout the day: Morning 5000K → Evening 4000K → Night 2700K[49]	Color Temperature	Artificial Lighting
	Color Preference	CPI > 80, warm-tone lighting to enhance emotional connection[9]	Color Preference Index (CPI)	Artificial Lighting

2.3.2. Key Light Health Indicators and Thresholds

Based on the relationship between indoor and outdoor lighting environment indicators and Light Health metrics, this study proposes healthy lighting values (Table2- 5 and Table2- 6) by integrating current regulatory lighting standards with contemporary research findings. These values serve as Light Health indicators and thresholds to guide subsequent design applications.

Table2- 5Outdoor Light Health Indicators and Health Thresholds

Source: Author

Light Health Issue	Regulation Indicator	Corresponding Lighting Environment Indicator	Standard Value	Threshold	Source Description (Standard & Health Values)
Visual comfort; limited activity & safety	Vertical illuminance	Vertical illuminance	No explicit benchmark	≥100 lx (working plane) or ≥80 cd/m² (eye level)	Standard value: Traditional lighting standards mainly focus on horizontal illuminance, lacking vertical illuminance indicators. Health value: Machi (2023) indicated that increased vertical illuminance can alleviate fatigue [50]; Zeng Shanshan (2020) suggested luminance ≥80 cd/m² to improve spatial orientation [49].
Circadian rhythm disruption; low mood	Natural light exposure duration	Daylight duration	≥1 hour (winter solstice standard)	≥2 hours exposure to >1000 lx daylight	Standard value: "Residential Design Code" requires ≥1 hour of sunlight. Health value: Adamsson et al. (2018) found significant positive correlation between >1000 lx daylight exposure and mood [51]; Sun Wenyao (2017) and Li Yuling (2018) emphasized community space daylight duration and vitality[4][30].

Table2- 6Indoor Light Health Indicators and Health Thresholds

Source: Author

Light Health Issue	Regulation Indicator	Corresponding Lighting Environment Indicator	Standard Value	Threshold	Source Description (Standard & Health Values)
Visual impairment	Horizontal illuminance (lx)	Illuminance	100–150 lx	≥300 lx (elderly) / ≥500–750 lx (reading/writing area) / ≥1000 lx	Standard value: According to "Building Daylighting Design Standard" [44], main rooms in residential spaces are recommended with daylight factor (DF) ≥1.0%, equivalent to 100–150 lx of natural light, serving as a

				(circadian regulation)	minimum daylight reference. Health value: Cui Zhe et al. (2016) indicated elderly require illuminance compensation [52]; Zeng Shanshan et al. (2020) suggested 500–750 lx for reading/writing areas [49]; Wang Rong (2018) noted 1000 lx can suppress melatonin secretion [57]. LEED (2014): Daylight credit requires ≥55% of usable space ≥300 lx; WELL recommends daylight exposure for circadian regulation.
Circadian rhythm disruption	Daylight factor (DF)	Daylight factor (DF)	≥1.0%–1.5%	≥2.0%–2.5%	Standard value: "Building Daylighting Design Standard" recommends DF ≥1.0% for main residential spaces [44]. Health value: Acosta et al. (2017) suggested DF >2% for hospital wards; Zhao Jianping et al. (2017) proposed ≥2.5% as health threshold [55][56]; WELL (2014) emphasizes maximizing daylight exposure to support mental health and circadian regulation.
	Illuminance schedule	Daytime light duration	No explicit benchmark	≥30 minutes (1000 lx)	Standard value: Not available. Health value: Cui Zhe et al. (2016) clinical study for elderly showed high-intensity cold white light exposure in the morning reduced nocturia by 35% (directly related to rhythm regulation) [52]; Adamsson et al. (2018) found >1000 lx daylight

					exposure duration positively correlated with emotional stability [51].
	Circadian Stimulus (CS)		No explicit benchmark	≥100 lx (CS ≥0.3)	Standard value: Not available. Health value: Zeng Shanshan et al. (2020) derived vertical illuminance ≥100 lx as CS ≥0.3 threshold based on ipRGC response model[49]; Hao Luoxi et al. (2017) verified in hospital lighting retrofit that CS ≥0.3 stabilizes staff circadian rhythms (melatonin phase shift <30 min) [24].
Low mood	Illuminance uniformity	Illuminance uniformity	≥0.4	≥0.7	Standard value: "Building Daylighting Design Standard" 4.0.5: minimum/average daylight ratio for residential spaces should not be lower than 0.4 [44]. Health value: Wang Rong (2018) found in classroom dynamic lighting experiment that Uo ≥0.7 group reduced anxiety scale (SAS) score by 21.3% ($p<0.01$)[57].

2.3.3. Definitions and Conceptual Clarification of Indoor and Outdoor Light Health Indicators

Outdoor Light Health Indicators:

(1) Duration of Natural Light Exposure

The duration of natural light exposure refers to the amount of continuous direct sunlight residents can receive each day. It is a core health factor for regulating circadian rhythms, improving mood, and enhancing spatial vitality. The Residential Design Code specifies a minimum of 1 hour of sunlight on the winter solstice. Epidemiological studies by Adamsson et al. indicate that when natural light exposure is extended to ≥2 hours with illuminance >1000 lx, residents' emotional and psychological states significantly improve[51].Scholars Sun Wenyao and Li Yuling also emphasize that the continuity and openness of daylight in community public spaces directly influence residents' activity levels and social interaction frequency [4][30].Therefore, this study proposes design strategies such as reducing excessive obstruction from buildings or trees and reasonably arranging open activity areas to ensure ≥2 hours of sunlight on the winter solstice with illuminance above 1000 lx, serving as a key standard for healthy natural lighting in community design.

(2) Illuminance (lx)

Here, illuminance refers to the minimum illuminance along a vertical direction where the value decreases. Ma Chi points out that appropriately increasing vertical illuminance in pedestrian areas helps reduce visual fatigue and improves spatial legibility[50].Research by Zeng Shanshan et al. found that using light-colored, high-reflectance materials for building façades can effectively enhance façade brightness, recommending eye-level luminance ≥80 cd/m² and vertical illuminance at work planes ≥100 lx to improve nighttime orientation and safety[49].

Indoor Light Health Indicators:

(1)Horizontal Illuminance (lx)

Horizontal illuminance measures the intensity of light on a specific work or activity plane in indoor spaces and directly affects visual work efficiency and visual fatigue. According to Building Daylighting Design Standard GB/T 50033－2013, the recommended daylight factor (DF) for main rooms in residential buildings is ≥1.0%, equivalent to natural illuminance of approximately 100－150 lx, serving as a minimum standard for indoor natural lighting[44].However, research by Cui Zhe, Ma Chi, and others indicates that elderly individuals require higher illuminance compensation (≥300–600 lx) due to decreased visual sensitivity, while reading and learning areas need ≥500–750 lx to meet visual task demands[50][52]； Wang Rong further suggests that for circadian rhythm regulation, indoor high-illuminance zones should reach ≥1000 lx to suppress melatonin secretion and enhance alertness[57]. Internationally, the WELL Building Standard emphasizes the support of natural light for physiological rhythms. Therefore, this study proposes graded illuminance requirements based on functional zones, prioritizing enhanced natural lighting in visual work areas.

(2)Daylight Factor (DF)

The daylight factor (DF) is a core metric for assessing indoor natural light levels, representing the percentage of outdoor illuminance received at a point indoors relative to the outdoor illuminance at the same time. The Building Daylighting Design Standard recommends DF ≥1.0% – 1.5% for main rooms in residential buildings[44].Health-focused studies further indicate that DF ≥2.0%–2.5% promotes more uniform natural light penetration, supporting circadian regulation and psychological comfort[55][56]. Therefore, this study proposes strategies such as enlarging daylight openings and using high-reflectance interior surfaces to achieve a healthy target of DF ≥2.5% in residential spaces.

(3)Illuminance Schedule — Morning High-Illuminance Exposure

The illuminance schedule measures the dynamic impact of natural light at different times of day on occupants, with morning high-intensity cold white light being particularly effective for circadian regulation. Clinical experiments by Cui Zhe et al. on elderly residents show that daily morning exposure to ≥1000 lx for ≥30 minutes reduces nocturnal urination by 35%, significantly improving sleep quality[52]. Adamsson et al.'s large-scale epidemiological study also confirmed that morning high-illuminance natural light exposure is positively correlated with emotional stability[51]. Therefore, this study recommends optimizing window-to-wall ratios and introducing east-facing daylight surfaces to ensure morning indoor natural illuminance of ≥1000 lx for at least 30 minutes.

(4)Indoor Illuminance Uniformity — Emotional Comfort and Visual Continuity

Illuminance uniformity (Uo) affects not only visual comfort but also occupants' emotional state. The Building Daylighting Design Standard GB 50033-2013 specifies that the minimum-to-average daylight ratio in residential spaces should not be less than 0.4[44]. Wang Rong's dynamic classroom experiments found that when Uo ≥0.7, students' anxiety levels decreased significantly (SAS scores reduced by 21.3%, $p<0.01$)[57]. Therefore, this study proposes prioritizing the improvement of indoor illuminance uniformity (recommended Uo ≥0.7) through high-reflectance diffuse materials, rational arrangement of light sources and windows, while ensuring horizontal illuminance meets standard requirements.

2.3.4. Prioritization of Indoor and Outdoor Light Health Indicators

2.3.4.1. Prioritization of Outdoor Light Health Indicator

The prioritization of outdoor Light Health indicators is illustrated in Figure2- 1. The details are as follows:

(1)Duration of Natural Light Exposure (h)

The primary condition for healthy street lighting is sufficient sunlight exposure. Only when the existing light environment meets the standards can residents’ activity rhythms and psychological comfort be ensured.

(2)Street-Level Illuminance (lx)

After ensuring adequate natural light exposure, attention should be given to the illuminance at street and alley levels. The lower levels are often overly dark due to high-density obstructions; overall illuminance must be increased to meet basic pedestrian safety and accessibility requirements. The prioritization order is shown in Figure 2-4.

2.3.4.2. Prioritization of Indoor Light Health Indicators

The prioritization of indoor Light Health indicators is shown in Figure2- 5. The details are as follows:

(1)Horizontal Illuminance (including morning high-exposure)

This is the most fundamental guarantee of indoor Light Health, determining whether work surfaces or activity areas receive sufficient light for reading, writing, household tasks, and other daily activities. Morning high illuminance, in particular, effectively regulates circadian rhythms and enhances alertness. Without adequate horizontal illuminance, optimization of other indicators cannot achieve their intended effect.

(2)Daylight Factor (DF)

Based on meeting the horizontal illuminance requirements, the daylight factor reflects the depth of natural light penetration and its distribution within the interior. It is a key parameter for indoor Light Health. Higher DF values indicate more uniform indoor lighting and more effective utilization of natural light, contributing to visual comfort and psychological well-being.

(3)Indoor Illuminance Uniformity (Uo)

Uniformity reflects the balance of light distribution. When horizontal illuminance and DF meet the requirements, uniformity naturally improves. Good illuminance uniformity prevents local bright-dark contrasts, reduces visual fatigue, and enhances emotional comfort and visual continuity, serving as a natural manifestation of the improvements achieved through horizontal illuminance and DF optimization.

2.4. Insights from Domestic and International Light Environment Renovation Cases

2.4.1. International Light Environment Renovation Cases

2.4.1.1. Venice: Current Situation and Renovation Measures

From the perspective of building density and layout, Venice’s urban structure is mainly composed of interconnected “alleys” and “islands,” as shown in Figure2- 6, where narrow streets—often only 1 - 2 meters wide—and small gaps between high-density buildings make it difficult for sunlight to reach the ground. Historically, most Venetian buildings are multi-story to adapt to limited land, which further exacerbates daylighting issues. Moreover, as Venice is a UNESCO World Heritage site, preservation regulations for historical buildings limit large-scale urban modifications, making it necessary to balance historical character with modern needs. Similarly, in Guangdong’s urban villages, many interiors retain ancestral halls as core cultural heritage, and even in areas without ancestral halls, large-scale demolition is generally undesirable, so renovation designs must improve the light environment while respecting existing structures.

Figure2- 4On-site Photos of Streets in Venice Historic Center

Source: Photographed by the author

As shown in Figure2- 7， in Venice, buildings have been enhanced through design modifications such as light-colored façades and reflective materials, roof and skylight renovations, removal of nonessential structures, creation of open spaces, and redesigned skylights and atriums, all of which improve street- and indoor natural lighting while preserving historical exteriors. For example, the renovation of St. Mark's Square Old Procuratie added windows and reconfigured interior spaces to significantly enhance natural lighting, the Fondaco dei Tedeschi Mall removed nonessential structures and redesigned skylights and atriums to increase daylight penetration, and the Negozio Olivetti Showroom added exterior windows, wooden lattices, and glass-tile floors to regulate indoor light and improve display quality.

Figure2- 5 The Procuratie Vecchie at St. Mark's Square; Fondaco dei Tedeschi Mall; Negozio Olivetti Exhibition Hall

Source: Archdaily

2.4.1.2. 25 Verde Apartments, Turin

This apartment complex integrates daylighting with green ecology. By arranging vegetation, the design regulates the light environment, enabling seasonal variations in sunlight and enhancing residential comfort. As shown in Figure2- 8, the architectural design emphasizes natural light penetration, with balconies and large glass windows in each unit ensuring ample indoor illumination while reducing reliance on artificial lighting. The vegetation layout optimizes the light environment: vertical greenery blocks excessive sunlight during summer, providing natural shading, while in winter, leaf loss allows more light to enter indoors. This strategy enhances residential comfort and creates dynamic visual effects throughout the seasons.

Figure2- 625 Verde Apartments, Turin, Italy

Source: Archdaily

2.4.1.3. Bridgepoint Active Healthcare, Canada

This project emphasizes the use of natural light to optimize patient recovery environments. The design extensively incorporates windows and transparent glass walls to bring daylight into the building while maintaining visual connections with the outdoors. As shown in Figure2- 9, by creating a warm and open hospital environment, Bridgepoint functions not only as a treatment facility but also as a community space that promotes patient rehabilitation, enhancing both indoor daylight quality and patients' emotional well-being.

Figure2- 7Bridgepoint Active Healthcare Light Environment Renovation, Canada

Source: Archdaily

2.4.1.4. Butaro Hospital, Rwanda

The hospital's architectural design prioritizes the introduction of natural light, particularly in patient rooms, using large windows and skylights. As shown inFigure2- 10, all beds are positioned to face windows, providing daylight, outdoor views, and ventilation. This design improves patient comfort, facilitates recovery, reduces the risk of airborne diseases, and lowers hospitalization time and treatment costs.

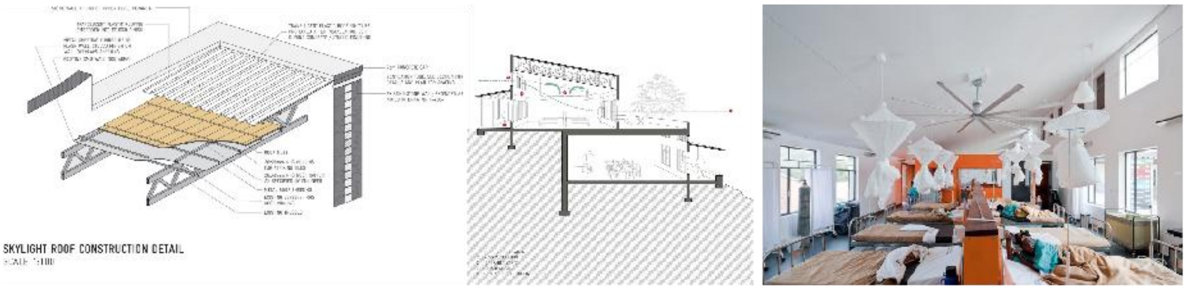


Figure2- 8Butaro Hospital Light Environment Components and Section, Rwanda

Source: Archdaily

2.4.1.5. Grøndalsvængets School, Copenhagen

Research shows that students in classrooms with more natural light outperform those in dimmer classrooms by over 20% in mathematics and reading tests. Applying this insight, the Grøndalsvængets School renovation uses the Velux modular skylight system to cover key teaching and activity areas. As shown in Figure2- 11, this design significantly increases indoor daylight, reduces dependence on artificial lighting, and creates a healthier and more energy-efficient indoor climate. The even and soft top lighting from the skylights reduces glare, creating a comfortable and harmonious environment that helps alleviate common issues such as headaches and fatigue.

Figure2- 9Grøndalsvængets School Modular Skylight Renovation, Copenhagen

Source: Archdaily

2.4.1.6. Ørsted Cultural Centre, Copenhagen

As shown in Figure2- 12, this renovation introduces a maximum amount of natural light by adding 16 roof skylights, installing glass openings high on internal walls, and creating an entrance glass curtain wall to improve light distribution. South-facing areas use highly transparent Low-E glass, while north-facing areas use insulated glass, all complemented by a smart system that automatically adjusts skylights and blinds according to environmental data, achieving an optimal balance between daylighting and thermal comfort.

Figure2- 10Oslo Cultural Center Skylight Design and Glass Renovation

Source: VELUX

2.4.1.7. Albertslund Residential Building, Copenhagen

This residential project introduces daylight into previously underlit central areas of the building using the prefabricated modular rooftop system called “Solar Prism.” As shown in Figure2- 13, the system effectively improves overall indoor daylighting and uniformity. Additionally, the system integrates daylighting with ventilation and solar energy utilization, providing standardized and cost-effective enhancements to indoor visual comfort while significantly reducing energy consumption.

Figure2- 11Albertslund Residential Modular Roof System

Source: VELUX

2.4.1.8. Solar Desalination Skylight, Chile

This skylight combines solar energy with seawater desalination technology to address lighting and water supply issues in informal settlements. As shown in Figure2- 14, solar energy powers seawater evaporation, which is condensed into freshwater, and the process also refracts sunlight into interior spaces, supporting daily activities such as studying and family meals. This innovative design significantly improves natural daylight conditions and provides sustainable drinking water for residents.

Figure2- 12Skylight Design and Actual Application Images

Source: VELUX

2.4.1.9. Frederiksbjerg School, Aarhus

The school design emphasizes sunlight as a dynamic light source. As shown inFigure2-15, windows are sized in tiers: largest in the central facade, smaller at the roof, and smallest near the ground. The large central windows create views for open areas, roof-top windows allow sunlight to reach deep into the building, and low windows invite children to sit and read or play. Careful solar shading devices prevent overheating and glare, and the patterned window arrangement creates a naturally diverse daylight experience, a concept successfully applied in other educational buildings by the same architectural firm.

Figure2- 13Frederiksbjerg School Façade Design, Aarhus

Source: Archdaily

2.4.1.10. Sweco Office Building, Aarhus

This project renovates a former 1899 paper mill into an open-plan office accommodating 180 employees. The 1959 sawtooth roof addition had deteriorated, reducing daylighting efficiency. As shown in Figure2- 16, 432 triple-glass north-facing skylight modules were installed in 9 rows, 63 of which include ventilation functions for fresh air intake and smoke exhaust during emergencies. This renovation improves natural daylight penetration, reduces reliance on artificial lighting, enhances indoor comfort, and gives the historic building renewed sustainable life.

Figure2- 14Sweco Office Building Rooftop Renovation, Aarhus

Source: VELUX

2.4.1.11. Federal Center Building 48, Denver

The daylighting renovation integrates circadian lighting standards into the building design. As shown in Figure2- 17, tall windows and numerous skylights maximize natural light to serve as the primary circadian stimulus. The design team changed the ceiling from black to white to enhance light reflection and used spectral analysis tools to ensure daylight exposure in open office areas meets circadian requirements. In enclosed interior spaces lacking daylight, occupants are guided to daylight-rich collaboration zones during the day.

Figure2- 15Renovation Design and Implementation of Building 48, Denver Federal Center

Source: GSA

2.4.1.12. Tomi Ungerer High School, France

The original three-row rooftop skylights, built in the 1990s, provided only manual ventilation and smoke extraction and gradually became insufficient. As shown inFigure2- 18, the renovation replaced these with an automated modular skylight system, which in summer reduces indoor temperatures through natural ventilation and in winter improves insulation. This intervention lowered overall school heating energy use by 5% and reduced energy use beneath the skylights by up to 38%, enhancing indoor daylight, comfort, and providing a healthy, stable learning environment year-round.

Figure2- 16Modular Skylight Renovation Design of Tomi Ungerer High School

Source: VELUX

2.4.1.13. The Drill Hall, London, UK

The Drill Hall, formerly the headquarters of the London Rifle Brigade, was renovated into a modern office space. The original glass roof, damaged and deteriorated over time, was replaced with a customized lightweight glass roofing system. As shown in Figure2- 19, the new roof consists of 123 prefabricated double-glass panels with solar-control coating and safety interlayers, improving daylight quality while reducing glare, replacing previous reliance on curtains during hot weather, enhancing both daylight access and year-round indoor comfort.

Figure2- 17The Drill Hall Glass Roof System

Source: VELUX

2.4.2. Summary of Renovation Approaches

Table2- 7Summary of International Daylighting Retrofit Approaches

Source: Author

Country/Region	Project Name	Reference Significance
Venice, Italy	Old Procuratie, Piazza San Marco	The renovation combines modern lighting systems with natural daylighting, transforming the dark interiors of the historic building into open and bright spaces.
Venice, Italy	Fondaco dei Tedeschi Mall Renovation	A large glass roof over the atrium introduces natural light into the central areas, improving daylighting in

		the deeper parts of the building.
Venice, Italy	Negozio Olivetti Showroom	Materials such as marble and glass, along with geometric design, disperse natural light throughout the space, creating soft and even illumination.
Turin, Italy	25 Verde Apartments	Optimized daylighting through large glass windows and strategic placement of greenery.
Canada	Bridgepoint Active Healthcare	Well-lit environments help improve patient mood, reduce stress, accelerate recovery, and enhance psychological comfort in hospitals or residential spaces.
Rwanda	Butaro Hospital	Passive solar design and natural ventilation optimize the existing building environment, improving healthiness in medical spaces.
Copenhagen, Denmark	Grøndalsvængets School	Utilizes natural light to improve student health, enhancing illumination in main teaching and activity areas with a modular skylight system.
Copenhagen, Denmark	Ørsted Cultural Centre	Additional roof skylights and high glass openings introduce more natural light, while a smart control system optimizes illumination, creating a healthy and energy-efficient indoor climate.
Copenhagen, Denmark	Albertslund Residential Building	"Solar Prism" rooftop system introduces daylight into previously underlit areas, integrating solar energy and smart systems to improve daylight uniformity.
Chile	Solar Desalination Skylight	Combines sunlight with seawater desalination to provide clean water for informal settlements, while refracted sunlight improves interior daylight for daily activities.
Aarhus, Denmark	Frederiksbjerg School	Window sizes are designed to guide natural light into different areas, creating a diverse daylight experience.
Aarhus, Denmark	Sweco Office Building	Modular daylighting systems installed on the sawtooth roof, combined with ventilation and energy-saving designs, create a consistent and comfortable natural light environment.
USA	Federal Center Building 48, Denver	Natural light is integrated to meet circadian lighting standards; skylights and windows maximize illumination, and color adjustments optimize the office environment.
France	Tomi Ungerer High School	Renovation replaced old skylights with modular systems, achieving automated ventilation and improved insulation, enhancing daylight and comfort while significantly reducing energy consumption.

London, UK	The Drill Hall	Custom double-glass roof system replaces the old roof, improving natural daylighting and safety while controlling glare and enhancing indoor comfort.

The summary of renovation and optimization measures for light-health-oriented projects abroad is presented inTable2- 7:

(1) Architectural design optimization: Multiple cases significantly improved the light environment through architectural design. The Old Procuratie at Piazza San Marco in Venice combined modern lighting with natural light to transform dark spaces; the Fondaco dei Tedeschi mall introduced natural light via a glass roof over the atrium; Negozio Olivetti skillfully dispersed natural light using marble and glass; Butaro Hospital provided ample natural light through windows and skylights; Grøndalsvængets School enhanced illumination with skylights; the Albertslund residence improved lighting uniformity using the “Solar Prism” system; the Solar-Powered Seawater Desalination Skylight combined solar energy and seawater desalination technology to enhance living conditions in informal settlements; and Frederiksbjerg School optimized light distribution through varied window sizes.

(2) Spatial layout improvement and light distribution optimization: Some projects improved light penetration through spatial layout adjustments, adhering to the principle of no demolition unless necessary. The Fondaco dei Tedeschi mall and Venice’s Old Procuratie guided natural light through redesigned atria and internal spaces; Butaro Hospital positioned patient rooms along the building’s exterior to admit more light; Frederiksbjerg School adjusted window sizes to optimize illumination; and Grøndalsvængets School improved light distribution and health outcomes through its skylight system.

(3) Ecological design combined with light optimization: Some projects emphasized the integration of ecological elements with the light environment. For example, the 25 Verde residence in Turin used vegetation layouts to regulate light, creating seasonal light variations and enhancing residential comfort.

(4) Building component design optimization: Several projects significantly improved the light environment through updating or replacing architectural components. Tomi Ungerer High School replaced its old system with modular skylights, enhancing illumination and reducing energy consumption; The Drill Hall in London installed a custom double-layer glass roof to reduce glare and enhance daylighting; and the Sweco office in Aarhus installed large-scale

modular skylights on its sawtooth roof, combined with ventilation and energy-saving design, to create a unified and comfortable natural lighting environment.

2.5. Chapter Summary

This chapter systematically reviewed the mechanisms through which the light environment affects human physiological and psychological health, demonstrating the necessity of light-health-oriented renovation in urban villages and establishing the theoretical and empirical basis for research on urban village renewal from a light-health perspective. First, based on the intrinsic link between light and health, and referencing typical light-health renovation cases in polar research stations, healthcare facilities, and other settings, the chapter highlighted the crucial role of light in regulating melatonin secretion, circadian rhythms, mood improvement, and promoting physical activity. Furthermore, by comparing domestic and international healthy building evaluation standards, it was found that current indicators mostly focus on visual comfort and energy efficiency, lacking consideration for rhythm regulation and emotional interventions. Additionally, based on the author's academic experience at Politecnico di Torino, cases in Europe and other countries were studied to examine how light environment improvements support health. For instance, field studies in Venice, which has spatial forms similar to urban villages, revealed the use of micro-renewal approaches, which also became a key entry point for this study. This gap forms the entry point of the present study. Therefore, this chapter serves as the theoretical and empirical foundation of the thesis, clarifying the research value of light-health in urban village renewal and providing a theoretical basis for subsequent field investigations and the development of design strategies.

Chapter3. Light Environment Survey of Urban Villages in Guangdong: A Case Study of Shipai Village

3.1. Overview of Urban Villages in Guangdong and Shipai Village

3.1.1. Light Climate Characteristics in Guangdong

The light climate, as an average state of natural light, includes sky illuminance, luminance variations, and the spatial distribution characteristics of light. Natural light is a key component of the light climate, consisting of direct sunlight, diffuse skylight, and ground-reflected light [44]. Direct sunlight passes through the atmosphere and strikes the ground, casting shadows on the shaded sides of objects; diffuse skylight, influenced by cloud cover, cloud type, and atmospheric particles, provides nearly uniform, non-directional illumination; ground-reflected light enhances the brightness of both the ground and the sky. Therefore, the rational utilization of natural light not only reflects regional light climate characteristics but also meets the daylighting requirements of building interiors.

China's vast territory exhibits significant variations in light climate characteristics, mainly affected by factors such as geographical location, latitude, and cloud cover. In general, northern regions are dominated by direct sunlight, while southern regions are dominated by diffuse sunlight. As shown in Figure3- 1, China is divided into five light climate zones, with Guangzhou located in Zone IV[44]. Guangzhou belongs to the subtropical maritime climate, characterized by high temperatures, abundant rainfall, and long sunshine hours, with an annual total solar radiation generally ranging from 4,400 to 5,000 MJ/m^2, and exceeding 5,000 MJ/m^2 near the Pearl River Estuary.

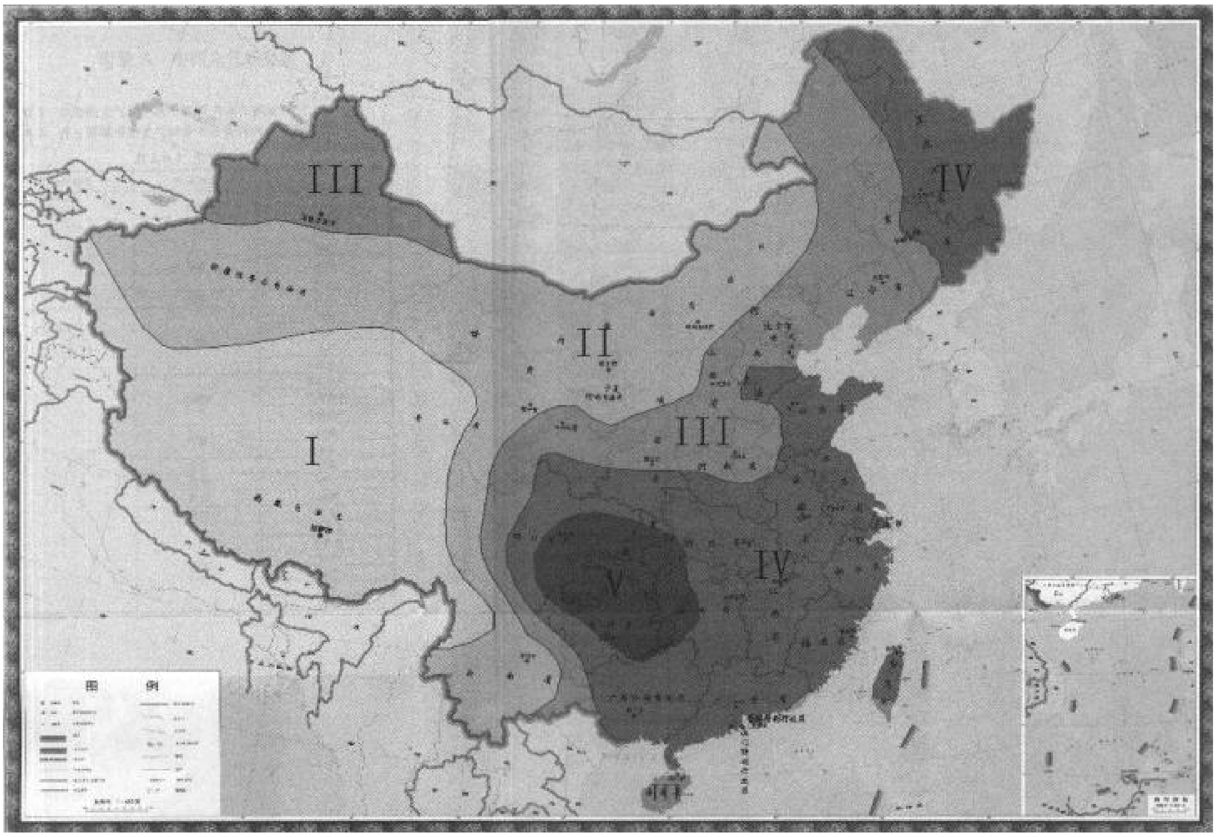


Figure3- 1China's Solar Climate Distribution Map

Source: Literature[44]

3.1.2. Rationale for Site Selection

Guangzhou, as the capital of Guangdong Province, has a highly active economy and has even been ranked as a global first-tier city by authoritative international institutions. However, behind the rapid urban development, the city still contains over 300 urban villages, which retain a large number of low-rise buildings and densely populated residential areas, with most land being privately or collectively owned, aging infrastructure, and insufficient public services. Against this backdrop, Guangzhou has initiated and advanced multiple urban village redevelopment projects, whose distribution is shown in Figure3- 2, achieving notable progress.

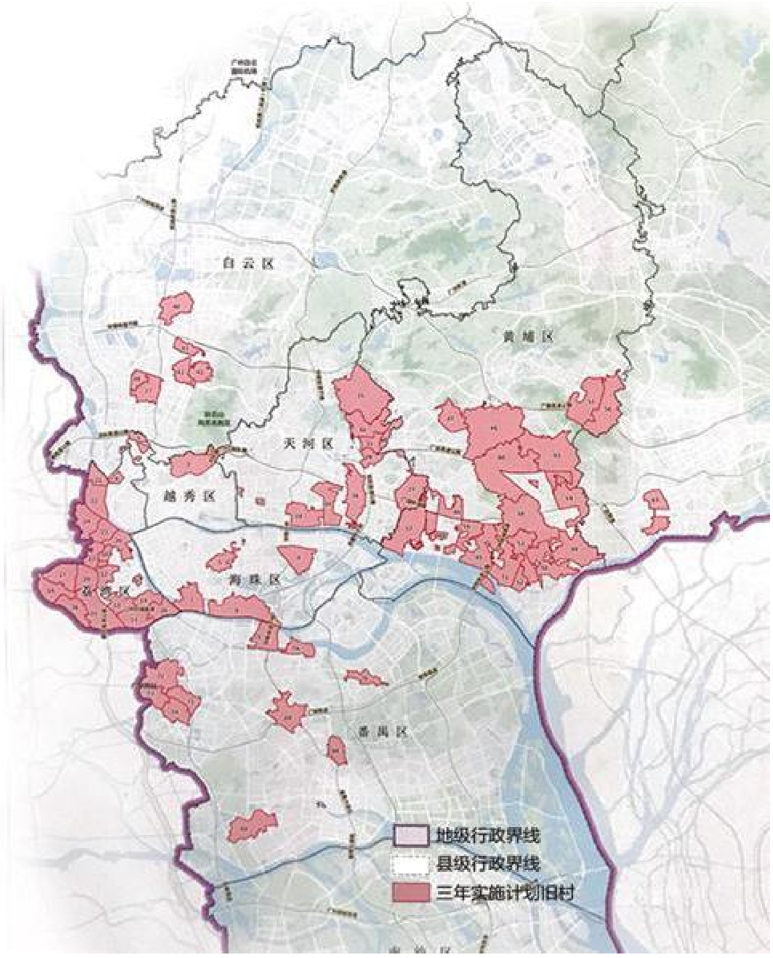


Figure3- 2Distribution Map of 83 Urban Villages Included in the Three-Year Implementation Plan (2020–2022)
Source: Official Website of Guangzhou Municipal People's Government

Among these urban villages, Shipai Village, located in the core area of Tianhe District, represents a typical example of Guangzhou’s urban villages(Figure3- 3). As shown in the location map in Figure3- 4, Shipai Village enjoys a superior geographical position within the core business district of Guangzhou. It is surrounded by major roads such as Tianhe North Road, Tianhe Road, and Huangpu Avenue, providing convenient transportation. Covering an area of 0.31 km², Shipai Village is adjacent to the city center’s commercial zone, with multiple bus and metro lines converging nearby, facilitating mobility for both residents and visitors.

Moreover, Shipai Village is in close proximity to several well-known universities, including South China Normal University and Jinan University. The surrounding area is densely equipped with commercial facilities, office buildings, and shopping centers such as Teemall and Taikoo Hui, making it a key development area within Tianhe District. With convenient transportation, developed infrastructure, and a rich cultural atmosphere, this advantageous location not only highlights the necessity for Shipai Village’s redevelopment but also makes it a typical pilot site for urban village renovation and urban renewal. Through the light-health-oriented redevelopment of Shipai Village, this study aims to explore a practical path for renovation while providing transferable experience for the redevelopment of other urban villages in Guangdong.

Figure3- 3Location of Shipai Village Site

Source: Author

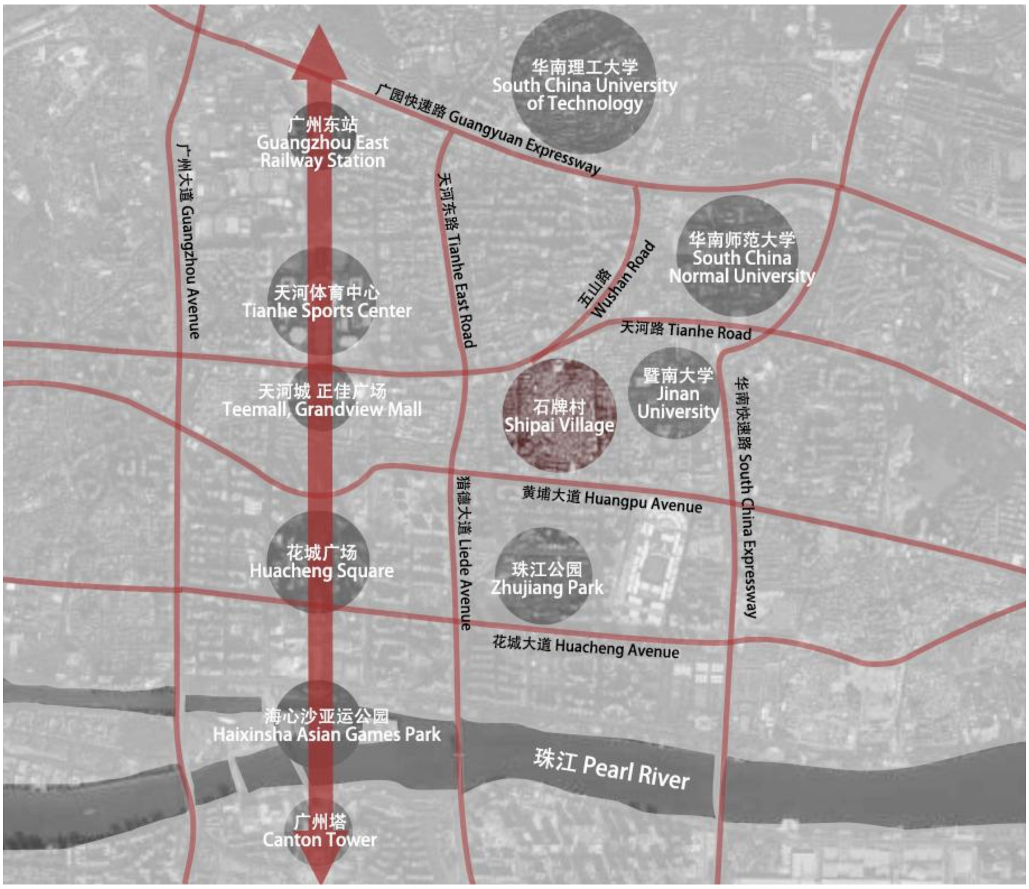


Figure3- 4Geographical Location of Shipai Village

Source: Author

Figure3- 5Surrounding Environment of Shipai Village

Source: Author

3.2. Current Light Environment of Shipai Village

3.2.1. Overall Light Environment Survey

Figure3- 6Site Photos of Shipai Village

Source: Photographed by the author

Table3- 1Measured Building Gap Data of Shipai Village

Source: Author

Range of Measured Minimum / mm	Range of Measured Maximum / mm	Common Minimum / mm	Common Maximum / mm	Range of Measured Minimum / mm
Building Gap Width Estimated Value / m	48.1	6900	~100	Building Gap Width Estimated Value / m
Total Length of Building Gaps	61000			Total Length of Building Gaps

Table3- 2Per Capita Residential Area Statistics of Shipai Village

Source: Author

Assuming an average of 3 floors per building and a resident population of 37,300.			
Building Footprint Area per Floor	Number of Floors	Population	Total Land Area
207176	3	37300	621528
Estimated Total Area of Urban Village / m²	Per Capita Residential Area / m²		
272600	16.66294906		

Based on on-site surveys and measurements in Shipai Village, I drew the following conclusions:

(1) Shipai Village exhibits a highly dense spatial layout, with generally poor light conditions that make healthy living difficult to ensure. The extreme lack of daylight is the most immediate impression of the village. As shown in Figure3- 6, almost all buildings within the site are “handshake” type structures. According to survey data in Table3- 1, the width of building gaps varies from 48.1 mm to 6,900 mm, but most are concentrated within a narrow range of approximately 100 mm to 2,500 mm. Such narrow gaps result in almost no natural lighting or ventilation for most buildings and also compromise residential privacy. The total length of building gaps is about 61,000 m, with gap-edge ratios of 18.95% and 15.03%, indicating that although gaps occupy a significant proportion overall, most are insufficient to provide effective daylight.

(2) Regarding residential area, calculations in Table3- 2 estimate the total area of Shipai Village to be 272,600 ㎡. Assuming an average of three floors per building, the total built-up area can reach 621,528 ㎡, accommodating a resident population of 37,300, resulting in a per

capita living area of only 16.66 ㎡, reflecting severe overcrowding under high-density conditions. To maximize benefits, self-built houses commonly reserve the top floor for the household head while renting out lower floors as commercial spaces, making all floors except the top the darkest and most poorly lit residential areas. Under this pattern, middle-floor residents rely almost entirely on narrow building gaps for daylight, living in poorly lit conditions. This not only exacerbates differences in living quality among floors but also weakens neighborly interactions and reduces community activities, leading to an overall decline in quality of life.

3.2.2. On-Site Measurement Data and Analysis of Outdoor Spaces

（1）Outdoor Spaces — Main Streets

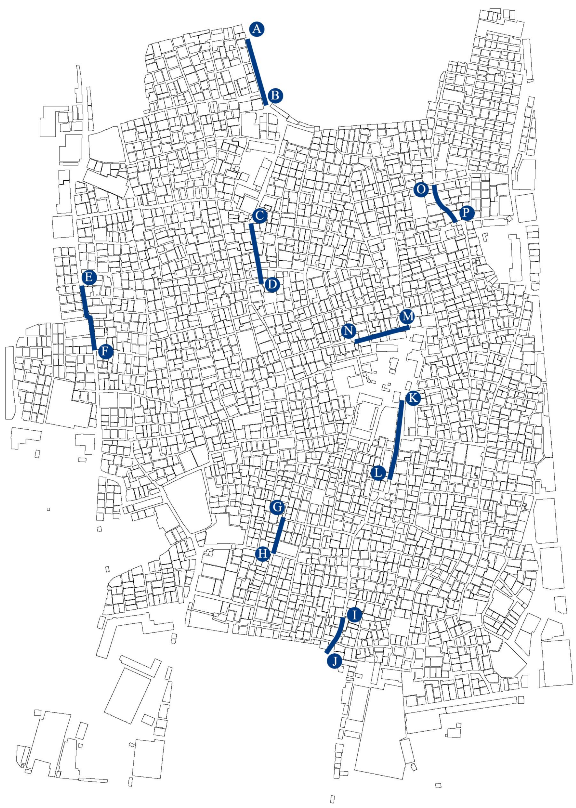


Figure3- 7Measurement Point Distribution of Main Street Light Environment

Source: Author

Table3- 3Measurement Results of Main Street Light Environment

Source: Author

Weather	Time	Location	Street Width (m)	Average Floors	Average Height Both Sides(m)	Street Height-to-Width Ratio	Illuminance (lx)	Minimum Illuminance(lx)	Average Illuminance (lx)
Cloudy	Morning	A-B	3.45	6	21.6	0.16	2002	2002	2164.33
	Noon						2235		
	Afternoon						2256		
	Night						218		
	Morning	C-D	3.5	7	25.2	0.139	250	250	264.73
	Noon						274		
	Afternoon						270.2		
	Night						123.9		
	Morning	E-F	2.65	7	25.2	0.105	67.1	47.9	56.33
	Noon						54		
	Afternoon						47.9		
	Night						153		
	Morning	G-H	4.6	8	28.8	0.16	132	125.3	82.57
	Noon						324		
	Afternoon						125.3		
	Night						536		
	Morning	I-J	1.8	5	18	0.1	289	289	305.67
	Noon						327		
	Afternoon						301		
	Night						285.9		
	Morning	K-L	7.1	6	21.6	0.329	3260	2570	2909
	Noon						2897		
	Afternoon						2570		
	Night						1758		
	Morning	M-N	1.6	8	28.8	0.056	158	158	185.33
	Noon						195		
	Afternoon						203		
	Night						17.4		
	Morning	O-P	6	6	21.6	0.278	6752	6690	6895.67
	Noon						7245		
	Afternoon						6690		
	Night						2.65		
Sunny	Morning	A-B	3.45	6	21.6	0.16	98700	84500	94200

Weather	Time	Location	Street Width (m)	Average Floors	Average Height Both Sides(m)	Street Height-to-Width Ratio	Illuminance (lx)	Minimum Illuminance(lx)	Average Illuminance (lx)
	Noon						99400		
	Afternoon						84500		
	Night						356		
	Morning	C-D	3.5	7	25.2	0.139	274	274	284.8
	Noon						291		
	Afternoon						289.4		
	Night						139		
	Morning	E-F	2.65	7	25.2	0.105	64.8	45	55.5
	Noon						56.7		
	Afternoon						45		
	Night						168		
	Morning	G-H	4.6	8	28.8	0.16	532	462	497.33
	Noon						462		
	Afternoon						498		
	Night						274.6		
	Morning	I-J	1.8	5	18	0.1	532	462	497.33
	Noon						462		
	Afternoon						498		
	Night						274.6		
	Morning	K-L	7.1	6	21.6	0.329	9078	9021	9043
	Noon						9030		
	Afternoon						9021		
	Night						715		
	Morning	M-N	1.6	8	28.8	0.056	713	713	714
	Noon						715		
	Afternoon						714		
	Night						214		
	Morning	O-P	6	6	21.6	0.278	83000	83000	83116.67
	Noon						2897		
	Afternoon						2570		
	Night						1758		

According to the distribution of measurement points shown in Figure3- 7 and the measurement results in Table3- 3, the characteristics of the main street light environment are as follows:

The data from the main streets reflect the influence of spatial morphology and height-to-width ratio on natural lighting. Street widths vary significantly, ranging from 1.6 m to 7.1 m, with wider streets exhibiting better daylight conditions. For example, on sunny days, wider streets such as H and F show illuminance levels far higher than narrower streets such as G and E. At the same time, all streets generally have low height-to-width ratios (0.05–0.33), indicating that streets are enclosed by tall buildings, with strong depth perception, which directly limits solar incidence angles and increases shadow coverage. As a result, small- to medium-sized streets have relatively low illuminance during the daytime.

Weather conditions have a significant impact on street lighting. On sunny days, wide streets such as H and F can reach illuminance levels of 80,000–90,000 lx, typical of direct sunlight. Under cloudy conditions, the same streets drop sharply to 6,000–7,000 lx, a reduction of over 90%, demonstrating the high sensitivity of illuminance to weather. In comparison, narrow streets such as G, E, and C maintain only a few hundred lux at midday on sunny days, and just tens to a few hundred lux under cloudy conditions, with some areas remaining dim throughout the day.

Considering different time periods, the daylight performance varies by street type. Wide streets (H, F) have sufficient illumination throughout the day, with minor fluctuations over time, indicating that open spatial conditions ensure stable daylight duration and intensity. Medium-width streets (D, A) have moderate daylight, with greater variation across different times and weather conditions. For example, at point A under cloudy conditions, illuminance is 2,002 lx in the morning, 2,235 lx at noon, and 2,256 lx in the afternoon; on sunny days, it can reach 90,000–100,000 lx. The narrowest streets (G, E, C) have insufficient daylight all day, further obstructed by shadows from adjacent tall buildings. Morning and afternoon illuminance is often lower and more unstable; for instance, at point H under cloudy conditions, illuminance drops from 67 lx in the morning to 54 lx at noon and 47.9 lx in the afternoon, approaching indoor dim-light levels.

（2）Outdoor Space — Secondary Streets

Figure3- 8Measurement Point Distribution of Secondary Street Light Environment

Source: Author

Table3- 4Measurement Results of Secondary Street Light Environment

Source: Author

Weather	Time	Location	Street Width (m)	Average Floors	Average Height Both Sides (m)	Street Height-to-Width Ratio	Illuminance(lx)	Minimum Illuminance (lx)	Average Illuminance (lx)
Cloudy	Morning	A-B	2.7	6	21.6	0.125	80	80	84.2
	Noon						86.7		
	Afternoon						85.9		
	Night						212.7		
	Morning	C-D	1.8	6	21.6	0.083	2.45	1.37	1.86
	Noon						1.37		
	Afternoon						1.75		
	Night						146.9		
	Morning	E-F	0.75	7	25.2	0.03	56.1	43.4	50.8
	Noon						52.9		
	Afternoon						43.4		
	Night						144.9		

Weather	Time	Location	Street Width (m)	Average Floors	Average Height Both Sides (m)	Street Height-to-Width Ratio	Illuminance(lx)	Minimum Illuminance (lx)	Average Illuminance (lx)
	Morning	G-H	2	6	21.6	0.093	80.1	80.1	82.57
	Noon						86.4		
	Afternoon						81.2		
	Night						264.1		
	Morning	I-J	1.8	8	28.8	0.063	2164	2101	2126
	Noon						2113		
	Afternoon						2101		
	Night						180.6		
	Morning	A-B	2.7	6	21.6	0.125	3057	2830	2942.33
	Noon						2830		
	Afternoon						2940		
	Night						254		
	Morning	C-D	1.8	6	21.6	0.083	813.6	813.6	823.53
	Noon						830		
	Afternoon						827		
	Night						147.8		
Sunny	Morning	E-F	0.75	7	25.2	0.03	1690	1690	1709
	Noon						1728		
	Afternoon						1709		
	Night						145		
	Morning	G-H	2	6	21.6	0.093	679	587.5	649.17
	Noon						681		
	Afternoon						587.5		
	Night						265		
	Morning	I-J	1.8	8	28.8	0.063	6035	5987	6054
	Noon						6140		
	Afternoon						5987		
	Night						182		

According to the measurement point distribution in Figure3- 8 and the results presented in Table3- 4, the characteristics of the secondary streets' light environment are as follows:

Firstly, the street height-to-width ratio and degree of spatial enclosure exert a significant influence on natural daylighting. This group of streets is extremely narrow, with widths ranging from a minimum of 0.75 m (C) to a maximum of 2.7 m (A). The streets are highly enclosed, with average building heights between 21.6 m and 28.8 m and an average of 6–8 floors. The resulting height-to-width ratios are extremely low, mostly below 0.1, with street C reaching only 0.03. Such narrow street canyons severely restrict the direct penetration of sunlight.

Secondly, weather conditions have a pronounced impact on street illuminance. Under cloudy conditions, all streets except B exhibit extremely low average illuminance throughout the day—for example, streets A and D average around 80 lx, C approximately 50 lx, and B falls below 2 lx, approaching dim indoor levels. Street E, however, maintains a daily average of roughly 2,100 lx under cloudy conditions, significantly higher than other narrow streets, suggesting the presence of localized openings or nodes that allow sunlight penetration. On sunny days, illuminance generally increases by a factor of 10–50; for instance, C rises from 50 lx to 1,700 lx, and B from 2 lx to over 800 lx, yet both remain far below the levels of primary streets. Street E continues to perform best, exceeding 6,000 lx, approaching the lower range of medium-width streets, indicating its morphological advantages within the context of small-scale urban streets.

Considering temporal variations, daylight fluctuations reflect the influence of spatial configuration. Most narrow streets (A, D, C) show minimal variation throughout the day, with changes below 10%, indicating strong shading from adjacent tall buildings that limit direct solar penetration at street level, leaving primarily diffuse daylight. Street E exhibits stable daylighting under both cloudy and sunny conditions, with daily variation only 2–3%, demonstrating that its spatial form effectively distributes natural light evenly.

Finally, regarding illuminance uniformity, most small-scale streets exhibit daytime uniformity between 0.85 and 0.99. Due to narrow spatial dimensions and predominance of diffuse light, natural daylight is relatively evenly distributed, with few localized high-intensity areas and high overall illuminance consistency.

（3）Outdoor Space — Public Spaces

Figure3- 9Measurement Points Distribution of Public Space Light Environment

Source: Author

Table3- 5Measurement Results of Public Space Light Environment

Source: Author

Weather	Time	Location	Length (m)	Width (m)	Length-to-Width Ratio	Average Surrounding Height	Illuminance (lx)	Minimum Illuminance (lx)	Average Illuminance (lx)
Cloudy	Morning	A	43.5	31.5	1.381	5floors	2079	2079	2209.33
	Noon						2358		
	Afternoon						2191		
	Night						2.92		
	Morning	B	45.7	11.4	4.009	6floors	2164	2101	2126
	Noon						2113		
	Afternoon						2101		
	Night						180.6		
	Morning	C	31	23.7	1.308	4floors	4310	4310	4440
	Noon						4620		
	Afternoo						4390		

Weather	Time	Location	Length (m)	Width (m)	Length-to-Width Ratio	Average Surrounding Height	Illuminance (lx)	Minimum Illuminance (lx)	Average Illuminance (lx)
	n								
	Night						8.85		
	Morning						453		
	Noon						439		
	Afternoon	A	43.5	31.5	1.381	5floors	542	439	478
	Night						3.2		
	Morning						6035		
	Noon						6140		
Sunny	Afternoon	B	45.7	11.4	4.009	6floors	5987	5987	6054
	Night						182		
	Morning						85900		
	Noon						86700		
	Afternoon	C	31	23.7	1.308	4floors	78980	78980	83860
	Night						8.95		

Based on the measurement point distribution in Figure3- 9 and the results in Table3- 5, the characteristics of the public space lighting environment are as follows:

Regarding natural daylighting, regardless of cloudy or sunny conditions, the three public spaces maintain daytime average illuminance levels between 2000–4500 lx (A: 2209 lx, B: 2126 lx, C: 4440 lx), significantly higher than the low-light conditions of enclosed lanes. These levels correspond to comfortable outdoor lighting conditions, sufficient to support typical outdoor activities such as social interaction, resting, or circulation. Space C exhibits the highest illuminance, exceeding 4000 lx, indicating that relatively open spatial configurations with lower surrounding building heights (only 4 floors) and reduced enclosure ratios are more favorable for daylight penetration.

Although weather conditions visibly influence daylight levels, the overall illuminance remains within a reasonable range. Under sunny conditions, illuminance values are generally higher than on cloudy days; however, none of the readings indicate extreme highs or lows, demonstrating that the public spaces within the site maintain good adaptability to varying weather conditions.

Temporal variation analysis shows that the lighting environment is stable throughout the day. The three measurement points exhibit minimal fluctuations in illuminance across morning, noon, and afternoon, without pronounced peaks or troughs caused by changes in solar altitude, providing continuous and consistent lighting conditions suitable for outdoor use.

In terms of illuminance uniformity, these spaces maintain very high consistency under both cloudy and sunny conditions (0.94–0.99). The consistently high uniformity indicates that the relatively large spatial scale, minimal obstructions, and low enclosure ratios facilitate even distribution of natural light, avoiding localized glare or shadowed zones, thereby offering visually comfortable and evenly lit public areas for residents.

3.2.3. In-site Measurements and Analysis of Indoor Spaces

(1) Indoor Spaces — Ground-floor Commercial Spaces

Figure3- 10Measurement Points Distribution of Ground-Floor Commercial Space Light Environment

Source: Author

Table3- 6Measurement Results of Ground-Floor Commercial Space Light Environment

Source: Author

Weather	Time	Location	Street Width (m)	Average Floor Count	Average Height Both Sides (m)	Street Height-to-Width Ratio	Illuminance (lx)	Minimum Illuminance (lx)	Average Illuminance (lx)	Lighting Uniformity
Cloudy	Morning	A	3	1.8	5.4	0.6	2037	1741	1961.07	0.888
	Noon						2105.2			
	Afternoon						1741			
	Night						1037			
	Morning	B	4.2	2.1	8.82	0.5	2.45	1.37	1.86	0.738
	Noon						1.37			
	Afternoon						1.75			
	Night						146.9			
	Morning	C	1.4	4	5.6	2.857	250	250	264.736	0.944
	Noon						274			
	Afternoon						270.2			
	Night						123.9			
	Morning	D	1.8	3	5.4	1.667	40.8	40.8	43.6363	0.935
	Noon						48			
	Afternoon						42.1			
	Night						9.56			
	Morning	E	3.2	2.5	8	0.781	1583	1583	1857.26	0.852
	Noon						1950			
	Afternoon						2038.7			
	Night						154			
	Morning	F	2.8	3.2	8.96	1.143	2068	1916	2098	0.913
	Noon						2310			
	Afternoon						1916			
	Night						1002			
Sunny	Morning	A	3	1.8	5.4	0.6	6157	6120	6179	0.99
	Noon						6260			
	Afternoon						6120			
	Night						167			
Sunny	Morning	B	4.2	2.1	8.82	0.5	716	716	775.336	0.923

Weather	Time	Location	Street Width (m)	Average Floor Count	Average Height Both Sides (m)	Street Height-to-Width Ratio	Illuminance (lx)	Minimum Illuminance (lx)	Average Illuminance (lx)	Lighting Uniformity
	Noon						795			
	Afternoon						815			
	Night						131			
	Morning						254			
	Noon	C	1.4	4	5.6	2.857	261	234	249.67	0.937
	Afternoon						234			
	Night						124			
	Morning						62100			
	Noon	D	1.8	3	5.4	1.667	60250	6180	42843.33	0.144
	Afternoon						6180			
	Night						13.5			
	Morning						5430			
	Noon	E	3.2	2.5	8	0.781	5597	5260	5429	0.969
	Afternoon						5260			
	Night						158			
	Morning						77800			
	Noon	F	2.8	3.2	8.96	1.143	78380	77800	78176.67	0.995
	Afternoon						78350			
	Night						860			

Based on the measurement point distribution inFigure3- 10 and the results in Table3- 6, the characteristics of the residential space lighting environment are as follows:

Firstly, spatial morphology has a significant impact on natural daylight penetration. The commercial units on the ground floor are generally small in scale, with single-room areas mostly ranging from 5 to 9 m², front widths between 1.4 and 4.2 m, and depths from 1.8 to 4 m. The spatial configurations can be categorized into two typical layouts: narrow front–shallow depth or shallow front–long depth. Variations in aspect ratio further influence daylight performance: units such as types A, B, E, and F have low aspect ratios (0.5–1.1), with nearly square or short-rectangular plans, facilitating relatively uniform daylight penetration from the street-facing façades. In contrast, types C and D exhibit higher aspect ratios, exceeding 1.6, with type C approaching 2.86, resulting in deeper plans where natural light penetration is significantly limited.

Secondly, weather conditions substantially affect the actual daylight performance. Under cloudy conditions, most units receive insufficient natural light during the daytime; for example, types B, D, and F require artificial lighting supplementation. Units adjacent to main streets benefit from more favorable street height-to-width ratios, and some are near open plazas, slightly improving daylight levels. In sunny conditions, overall illuminance increases significantly, and differences between measurement points become more pronounced.

Thirdly, daylight performance varies across different times of day. Units located on streets with higher height-to-width ratios (e.g., A, E, F) show relatively stable illuminance throughout the day, with smooth transitions from morning to afternoon. In contrast, units on streets with poor height-to-width ratios (e.g., B, D) exhibit significant illuminance fluctuations, relying heavily on direct sunlight, indicating that internal daylight levels are strongly dependent on street proportions and spatial openness.

Finally, regarding illuminance uniformity, most units exhibit relatively high daytime uniformity (0.85–0.99). However, due to small room sizes and limited light sources, localized dark areas may still occur. Notably, unit D shows extremely low uniformity under sunny conditions, with a value of only 0.144, indicating that deep areas receive insufficient daylight, resulting in uneven light distribution and visually dim conditions, which are inadequate for normal occupancy.

(2) Indoor Spaces — Residential Units

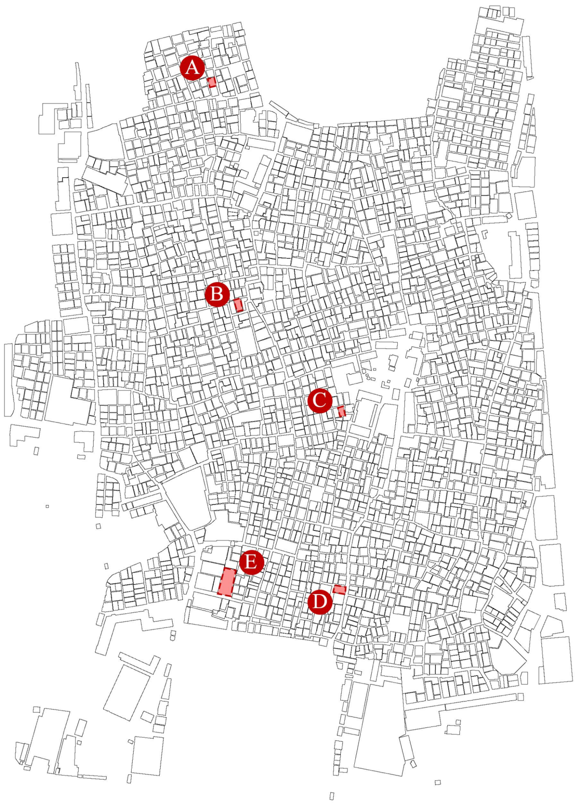


Figure3- 11Measurement Points Distribution of Residential Space Light Environment

Source: Author

Table3- 7Residential Space Form and Layout Data

Source: Author

Location	Window Type	Orientation	Floor Level	Floor Height (m)	Front Width (m)	Depth (m)	Aspect Ratio	Area (㎡)
A		Northeast	1	3.6	3	4	1.333	12
B	Sliding Windows on Both Sides	Northeast	3	10.8	3	4.5	1.5	13.5
C		Northwest	5	18	2.45	3.3	1.347	8.085
D		Northeast	4	14.4	4.5	5	1.111	22.5

Location	Window Type	Orientation	Floor Level	Floor Height (m)	Front Width (m)	Depth (m)	Aspect Ratio	Area (㎡)
E		Southeast	6	21.6	3	5	1.667	15

Table3- 8Residential Space Lighting Environment Measurement Results

Source: Author

Weather	Time	Location	Illuminance (lx)	Minimum Illuminance (lx)	Average Illuminance (lx)	Lighting Uniformity
Cloudy	Morning	A	78	78	80.86666667	0.965
	Noon		80.6			
	Afternoon		84			
	Night		230			
	Morning	B	87	87	91.46666667	0.951
	Noon		95.4			
	Afternoon		92			
	Night		218			
	Morning	C	2543	2041	2291.1	0.891
	Noon		2289.3			
	Afternoon		2041			
	Night		15.7			
	Morning	D	1068	985	1120.333333	0.879
	Noon		1308			
	Afternoon		985			
	Night		92.6			
	Morning	E	6858	6684	6972.333333	0.959
	Noon		7375			
	Afternoon		6684			
	Night		6.65			
Sunny	Morning	A	2784	2784	2872.333333	0.969
	Noon		2983			
	Afternoon		2850			
	Night		168			
	Morning	B	268	268	280.3333333	0.956
	Noon		290			
	Afternoon		283			

Night		141			
Morning		6039			
Noon	C	6189	5877	6035	0.974
Afternoon		5877			
Night		197			
Morning		88400			
Noon	D	87500	86270	87390	0.987
Afternoon		86270			
Night		1560			
Morning		83480			
Noon	E	83210	83000	83230	0.997
Afternoon		83000			
Night		4.7			

Based on the distribution map of measurement points (Figure3- 11) and the measurement results (Table3- 7Table3- 8), the characteristics of the residential space lighting environment in Shipai Village are as follows:

First, spatial morphology has a significant impact on natural daylighting. The residential units in Shipai Village are predominantly small apartments, with façade widths ranging from 2.45 to 5 m, depths between 3 and 5 m, and unit areas approximately 8–22 ㎡, mainly single-room layouts. The length-to-width ratios of most units fall within 1.1–1.6. All units employ sliding windows on both sides, with orientations including northeast, north, northwest, and southeast. Building floors range from 1 to 6 stories, with heights between 3.6 m and 21.6 m, consistent with typical self-built residential units in urban villages and their corresponding windowing conditions.

Second, weather conditions and different times of day significantly influence actual daylighting performance. Under cloudy conditions, low-floor units with unfavorable orientations (points A and B) experience illuminance of only 80–90 lx throughout the day, failing to meet basic daytime visual comfort requirements and necessitating artificial lighting almost continuously. Units C, D, and E, benefiting from higher floors or favorable orientations, maintain 2000–7000 lx, well above the minimum illuminance requirement (300–500 lx). Under sunny conditions, illuminance in units A and B increases, with A reaching approximately 2800 lx, generally sufficient for comfort, whereas B remains relatively low (≈280 lx). Unit C stabilizes around 6000 lx, offering suitable light conditions. Units D and E exhibit extremely high illuminance (up to 80,000–87,000 lx), likely due to direct solar exposure on south- or southeast-facing façades.

Finally, regarding illuminance uniformity, overall values are generally above 0.87, indicating relatively even light distribution. However, due to typical single-aspect windows and unit depths of 3–5 m, under sunny conditions most natural light concentrates within 1–1.5 m from the window. Interior areas such as deep room zones, bedside areas, and work surfaces like desks often experience insufficient daylight.

3.2.4. Daily Activities and Space Usage of Residents

The daily activities and spatial usage patterns of Shipai Village residents show clear differentiation (Table3- 9). Elderly residents predominantly rely on public spaces such as squares, senior centers, and village entrances for leisure, social interaction, and shopping. Local landlords focus mainly on rental activities, forming a daily pattern centered around the village entrance. The middle-aged and younger adult population depends more on residential and work-related spaces. Merchants, such as Mr. Huang, center their activities around shops, spending long periods there and relying heavily on nighttime lighting. Homemakers primarily occupy kitchens, balconies, and living rooms. Migrant workers and employed youth work outside the village during the day and return to rented units at night, with daily life and study highly dependent on artificial lighting. Children and adolescents mainly use schools and homes, with limited engagement in public activity spaces. Overall, spatial usage in Shipai Village presents a public–residential–commercial gradient, highlighting the elderly's dependence on public activity spaces while reflecting the middle-aged, youth, and children's strong need for adequate lighting in residential and study environments.

Table3- 9Interview Records of Various Population Groups in Urban Villages

Source: Author

ID	Name	Gender	Age	Background / Identity	Daily Activities
01	Grand ma Huang	F	68	Retired staff from Zhongshan Third Hospital, from Zhuhai	Spends much of the day at the senior center, playing mahjong and dancing with friends; in the afternoon rests under trees in the square; in the evening buys groceries and cooks for her grandchildren.

02	Grand ma Pan	F	63	Local villager, owns property for rental	Manages tenants at the village entrance and shows apartments; mostly active within the village but does not reside there.
03	Mr. Huang	M	45	Runs a noodle shop for 5 years; family lives in the village	Works in his shop all day, opens early and closes late, rarely leaving the premises; minimal weekend rest; relies heavily on artificial lighting to maintain the shop, with high electricity costs; lives in the upper floors above the shop.
04	Xiao Jing	F	10	Daughter of the noodle shop owner, attends Yuhua School; has been in Guangzhou with parents for 5 years	During weekdays, attends school with sufficient daylight; after school returns home to the upper floor of the shop to do homework.
05	Sister Huang	F	42	Housewife from Hunan with two children	Spends the day doing household chores: laundry, cleaning, kitchen and balcony use; in the evening takes care of children and prepares dinner for the family.
06	Uncle Zhang	M	65	Local villager, former village militia, owns rental property	Rarely resides in the village; manages tenants at the village entrance; when no tenants are present, socializes with other landlords in the square.
07	Xiao Cai	M	9	Local, student at Shipai Elementary; family has moved out of the village	Attends school during the day; after school plays briefly on the playground with classmates; buys snacks at nearby shops; family no longer resides in the village.
08	Mr. Liu	M	28	Local employee, works nearby, in Guangzhou for 3 years	Not present in the village during the day; returns to rental at night; sometimes stays home on weekends, but mostly goes out.
09	Xiao Deng	F	22	Intern in the internet industry, studied in Guangzhou	Works during the day; returns home at night to cook for the next day; mostly stays home on weekends to complete schoolwork, requiring artificial lighting.
10	Mr. Wang	M	26	Recent graduate, working in the internet industry	Almost never in the village during weekdays; often works overtime at night; spends weekends at home or outside the village; artificial lighting needed when staying home.

3.3. Summary of Light Environment Issues in Shipai Village

3.3.1. Current Light Environment and Problem Analysis

The current light environment in Shipai Village exhibits clear dual impacts on both physiological and psychological aspects (Table3- 10).

From a physiological perspective, different user groups have distinct spatial lighting requirements. Elderly residents primarily spend time in the village square, under tree shade, or in the senior center, relying on natural light to meet their needs for leisure and health. Shop operators, working long hours indoors, are heavily dependent on artificial lighting. Migrant workers and young office employees primarily use residential spaces at night during weekdays and during the day on weekends, making inadequate daylight exposure a prominent issue. Children and adolescents, whose daily activities center on schools and homes, also have strong demands for natural light to support learning.

From a psychological perspective, public and residential spaces play a crucial role in supporting social interaction and activity participation. Elderly residents engage socially in public spaces, while landlords, due to rental management, center their daily activities around the village entrance. Homemakers are mainly active in kitchens, balconies, and other household areas. Young adults often stay home or occupy public spaces briefly.

Overall, insufficient daylight in Shipai Village not only compromises residents' daily convenience and health but also constrains their ability to fulfill social and activity needs.

Table3- 10Analysis of Population Behavior and Light Health Issues

Source: Author

Impact Dimension	Light Environment-Related Factors	Interviewees / User Groups	Typical Activities	Exposed Contradictions / Issues
Physiological Impact	High building density, severe shading	Huang Jie, Huang Xian, Liu Xian, Xiao Deng, Wang Xian	Cooking, residential living, office/work/study	Deep interior spaces and poor orientation; kitchens and desks often located away from windows;

				ground-floor shops rely on artificial lighting long-term → visual strain, dim and inconvenient spaces.
	Insufficient outdoor daylight	Huang Nainai, Zhang Bobo, Xiao Cai, Xiao Jing	Sunbathing, exercise, leisure activities	Very few public spaces (only 3); elderly use them for sun exposure, children and students for activities; spaces are overcrowded, and dim streets reduce safety and convenience.
	Lack of sunlit green areas	All groups	Passing through, resting, socializing	Scarce greenery and absence of continuous green belts; public activity spaces lack sunlight, causing heat accumulation and reduced physical activity.
	Dark, enclosed spaces	Xiao Deng, Huang Jie, Liu Xian, Wang Xian	Staying at home / socializing	Extended indoor stay + low daylight → reduced willingness to move, negative effects on mood.
Psychological Impact	Activity spaces lacking daylight	Huang Nainai, Xiao Cai, Xiao Jing	Playing chess, dancing, children's play	Limited, crowded activity areas with poor lighting; some users abandon participation.
	Overall poor natural daylight in Shipai Village	All groups	Residential use / neighborhood interaction	Most activity areas lack natural light for extended periods; reliance on

	artificial lighting; oppressive residential floors → decreased neighborhood interaction.

3.3.2. Opportunities and Challenges of the Light Environment in Shipai Village

Based on the simulated sunlight duration diagrams for the summer solstice (Figure3- 12) and winter solstice (Figure3- 13), it can be observed that certain areas within Shipai Village receive up to eight hours of sunlight, indicating that even during the winter season, when the solar altitude is relatively low, the village as a whole maintains a basic level of natural illumination. However, the extremely compact building layout and the widespread “handshake building” phenomenon result in high-density construction that severely limits sunlight access in localized areas, such as lower floors, narrow streets, residential units, and north-facing rooms. These shadowed zones reduce the availability of natural light for basic daily activities, decrease social interaction, and constrain public space use. During the winter solstice, the lower solar altitude further exacerbates mutual shading between buildings, intensifying existing sunlight-deprived areas. Many spaces become dependent on artificial lighting, which can easily lead to visual fatigue.

7

Figure3- 12Sunlight Duration Simulation in Shipai Village on the Summer Solstice (June 22)

Source: Author

Figure3- 13Sunlight Duration Simulation in Shipai Village on the Winter Solstice (December 22)

Source: Author

3.4. Chapter Summary

This chapter takes Shipai Village in Guangzhou as the case study, conducting systematic site surveys, light environment measurements, and resident interviews to clarify the current light environment in high-density urban villages and its impact on residents' health. Starting from the local solar climate characteristics of Guangdong, the study reveals that Shipai Village suffers from severe natural lighting deficiencies due to high building density, narrow interstitial streets, and continuous self-built extensions by residents, forcing heavy reliance on artificial lighting.

Subsequently, indoor and outdoor light environment data were collected across various spatial types—including primary and secondary streets, public spaces, commercial units, and residential units—under different times of day and weather conditions, identifying spatial deficiencies in natural illumination. Interviews with residents across age groups provided insight into their daily activities and spatial use, highlighting the physiological and psychological impacts of inadequate lighting. This analysis clarifies the conflicts between the existing light environment and the actual needs of the population, demonstrating that light-health-oriented interventions in urban villages should not only aim to improve measurable indicators but also guide residents toward healthier lighting behaviors. The findings of this chapter provide a solid empirical foundation for the subsequent development of light-health-oriented renewal strategies.

Chapter4. Simulation-Based Optimization of Typical Light-Health Problem Spaces in Urban Villages

4.1. Typical Light-Health Spatial Prototypes in Urban Villages

Before analyzing the indoor and outdoor space prototypes, this study classifies the spatial types in Shipai Village based on spatial morphology, scale, function, and daylighting conditions. Outdoor spaces are categorized into primary streets, secondary streets, and public spaces according to their height-to-width ratios (H/W) and degrees of openness. Indoor spaces are divided into ground-floor commercial units and residential units based on their functional attributes and daylighting sources. This classification clarifies the light environment characteristics of each spatial type and provides a systematic foundation for the subsequent simulation and optimization of typical light-health-related spatial problems.

4.1.1. Summary of Outdoor Space Prototypes

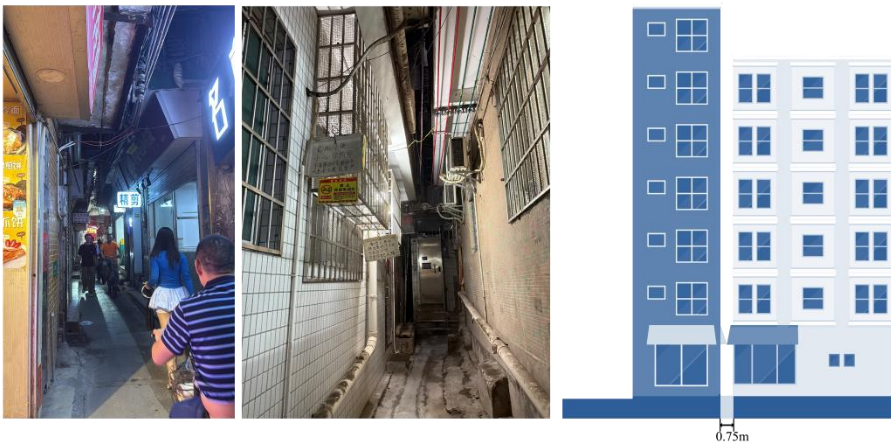
The typical outdoor spaces in Shipai Village can be categorized into three types: primary streets, secondary streets, and public spaces within the village. As shown inFigure4- 1, the widths of primary streets range from 3.45 m to 7.1 m, with an average building height of 6–8 floors and side elevations between 21.6 m and 28.8 m, resulting in a height-to-width ratio (H/W) of 0.139–0.329. Streetfronts are densely lined with commercial units, and elements such as awnings and signage introduce additional shading. Overall, natural lighting is acceptable, but localized shadow bands occur due to building H/W ratios and obstructions like signage, causing lower illuminance in some areas.

Secondary streets are extremely narrow, ranging from 0.75 m to 2.7 m in width, flanked by 6–8-story buildings with heights between 21.6 m and 28.8 m. The H/W ratio is very low—most below 0.1—creating a typical elongated, enclosed street form. Both primary and secondary streets are strongly affected by building enclosures, with secondary streets experiencing particularly severe depth-induced shading that limits daylight penetration at the street level. While primary streets are wider, longitudinal shadows still exist. Some secondary streets have partial openings that allow limited light access, resulting in slightly better illuminance compared to other narrow alleys.

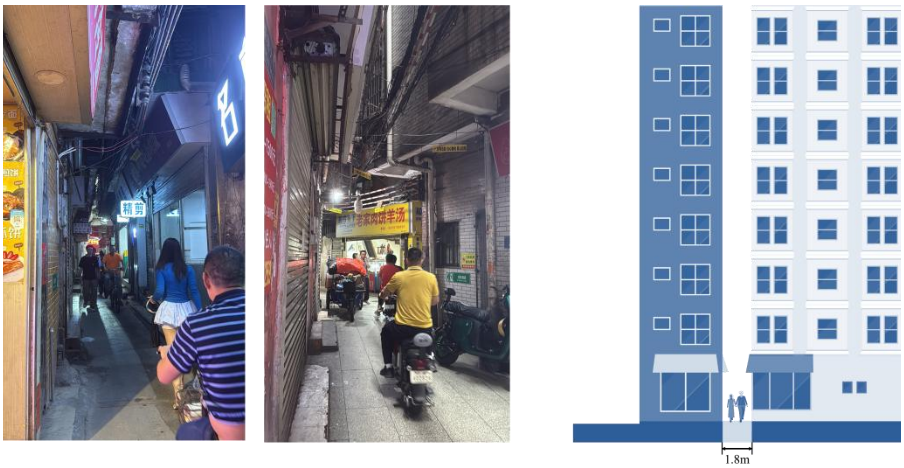
Village public spaces, such as pocket plazas, typically function as locally open nodes. These spaces are relatively large in scale with low enclosure, representing the main areas of natural light exposure within the village. Their moderate length-to-width ratios prevent overly elongated or excessively deep forms, enabling relatively sufficient daylight duration. However, dense tree canopies and unauthorized vertical extensions by residents can still compromise these otherwise favorable lighting conditions.

Figure4- 1Outdoor Space Main Street Prototype Diagram

Source: Author


0.75m


1.8m


1.8m


2.7m

Figure4- 2Schematic Diagram of the Minor Street Prototype in Outdoor Spaces

Source: Author

4.1.2. Summary of Indoor Space Prototypes

The typical indoor spaces in Shipai Village can be categorized into ground-floor street-facing commercial units and self-built residential units. As shown in Figure4- 1Figure4- 2, ground-floor commercial spaces are small in scale and tightly arranged, often featuring narrow, elongated single-aspect layouts. Individual units generally range from 5–9 ㎡ in area, with frontages of 1.4–4.2 m and depths of 1.8–4 m. Shops located along main roads or wider streets benefit from higher street openness due to favorable height-to-width ratios, allowing natural light to penetrate more easily. In contrast, units deeper within alleyways or internal clusters suffer from limited daylight, particularly in deeper spaces where illuminance rapidly decreases with depth. Daylight factors (DF) and horizontal illuminance are often insufficient, meaning most ground-floor shops currently rely on artificial lighting throughout the day.

Residential units are predominantly self-built, with frontages of 2.45–5 m, depths of 3–5 m, and areas of approximately 8–22 ㎡, usually arranged as single rooms. Their length-to-width ratios typically range from 1.1–1.6, forming near-square or slightly elongated rectangular layouts. Similar to commercial spaces, residential units exhibit significant front-to-back luminance differences due to depth, resulting in low illuminance uniformity—making them a representative typology of inadequate light-health conditions in Shipai Village. Residential floors span 1–6 stories, with building heights ranging from 3.6–21.6 m, leading to situations where upper-floor units enjoy better daylight while lower-floor units are heavily shaded.

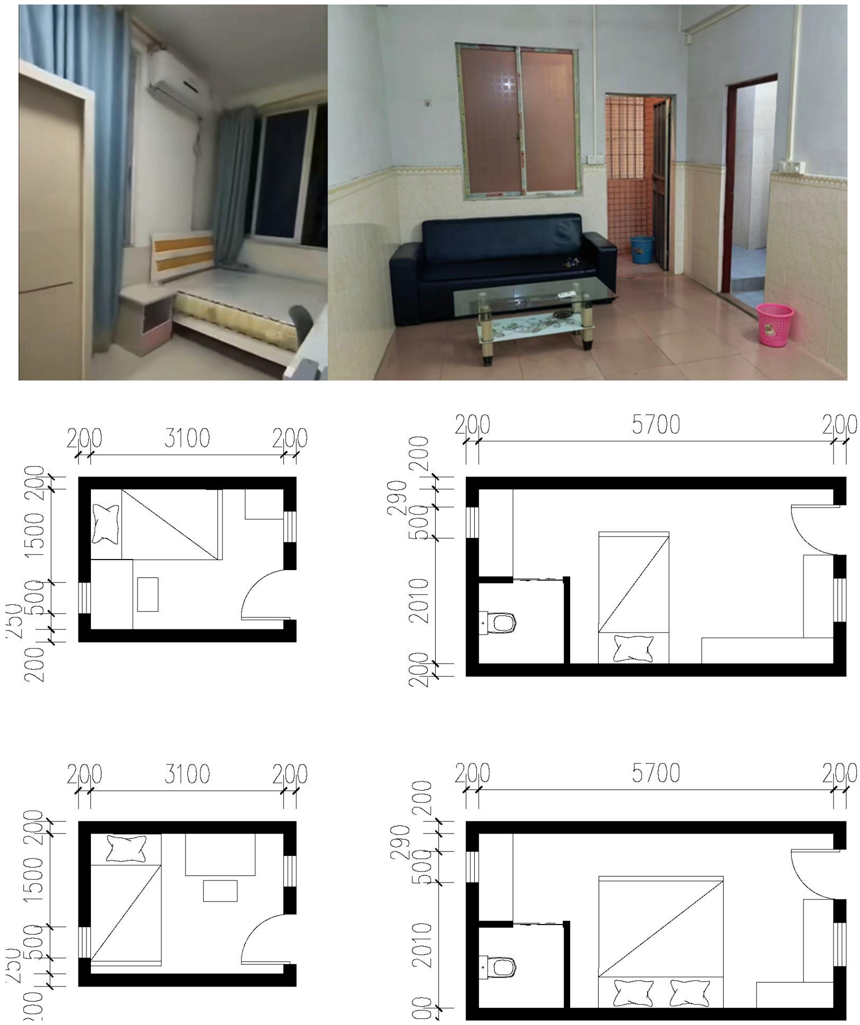


Figure4- 3Prototype Floor Plan of Indoor Space 1:150

Source: Author

4.2. Outdoor Prototype Space Simulation and Optimization

The outdoor prototype spaces in the urban village primarily comprise two main types: building cluster spaces and street/alley spaces. Therefore, simulations are conducted on these two prototype types to explore optimization strategies applicable to outdoor environments. In this process, the principle of “micro-renewal” is followed—prioritizing passive daylight improvement measures, such as the installation of light-guiding components, based on the existing spatial structure. Only when all feasible daylight optimization measures have been implemented and the required daylight levels and light-health activity durations remain insufficient will partial demolition or reconstruction be considered as a last resort.

4.2.1. Light-Health Issues and Simulation Optimization of Building Cluster Prototypes

Before conducting the simulation of building cluster modifications, this study first clarifies the premise and principle of such interventions. It adheres to the “micro-renewal” approach, meaning that demolition is considered only as a last resort—only after all feasible daylight improvement measures have been implemented. Therefore, the simulation of cluster-scale modification focuses on exploring minimal and localized interventions when passive daylighting strategies fail to sufficiently enhance illumination levels or extend light-health activity duration, aiming to identify the most effective methods for improving daylight efficiency with minimal intervention.

4.2.1.1. Simulation of Different Demolition and Modification Strategies for Building Clusters

(1) Establishment of a 7×12 Prototype Cluster

Due to variations in building scale, height, and street width in the original site, it is difficult to control variables uniformly. Therefore, a standard residential unit of 9×5×18 m is used to form a 7×12 building cluster for simulation analysis, as shown in Figure4- 3 andFigure4- 5.

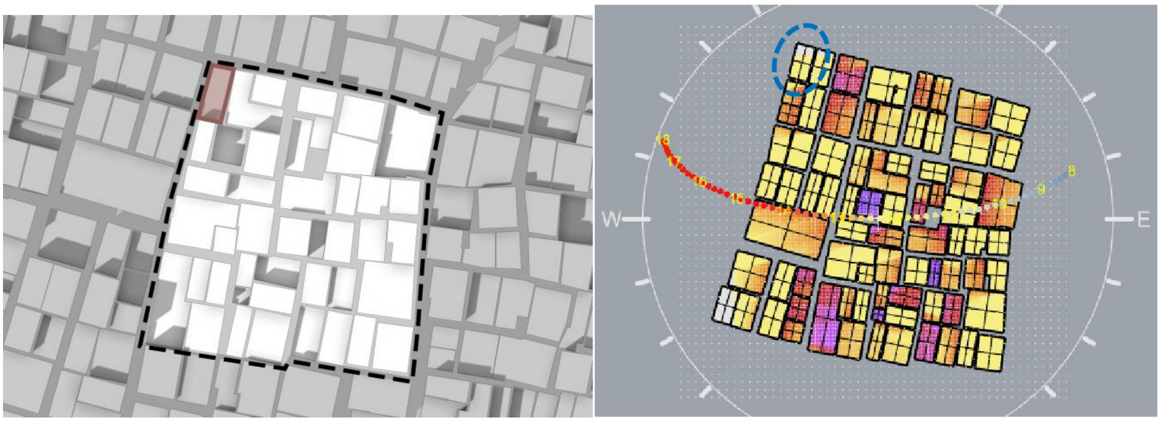


Figure4- 4Existing Building Cluster Morphology and Sunlight Hours Simulation

Source:Author

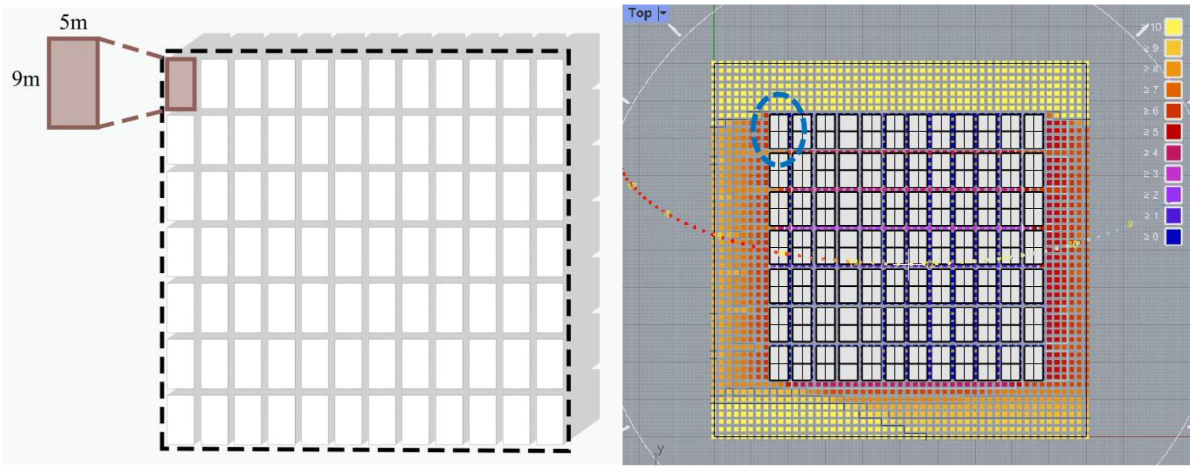


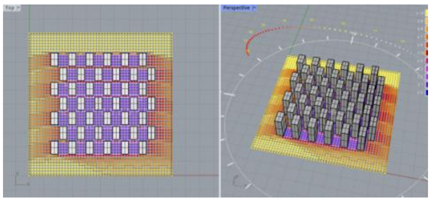
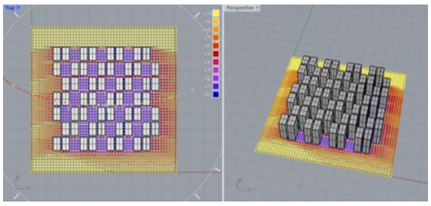
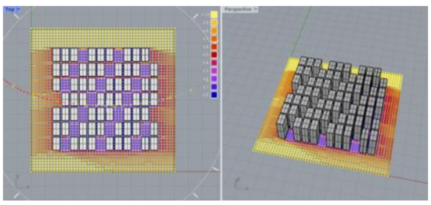
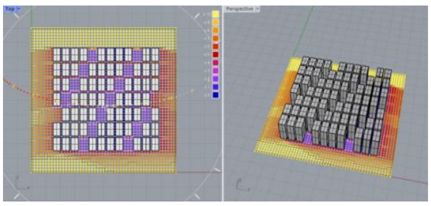
Figure4- 5Sunlight Hours Simulation of 7×12 Building Cluster Morphology

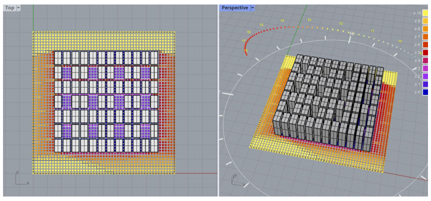
Source: Author

(2) Simulation of Cluster Demolition with Spacing Strategy

Table4- 1Simulation of Area Calculation for Intermittent Demolition Method

Source: Author

Demolition Method	Demolition Simulation	Demolition Area(m^2)	Non-Sunlight Ratio (Non-Sunlight Area /Total Area)	Sunlight Ratio (1 – Non-Sunlight Ratio)
1		19.278	0.211265	0.788735
2		12.852	0.293351	0.706649
3		9.639	0.342600	0.657400
4		7.344	0.375871	0.624129

5		6.426	0.383285	0.616715

Based on the simulation in Table4- 1, the author calculated the daylight improvement efficiency and relative demolition ratio for the staggered demolition method, as shown in Table4- 3.

Table4- 2Daylighting Efficiency of the Intermittent Demolition Method

Source: Author

Design Variation	Change in Demolished Area (m²)	Daylighting Improvement Change (%)	Improvement per Unit Area (%/m²)	Relative Demolition Ratio (Proportion of each step's demolition to the previous scheme's area)
1→2	6.426	8.21	1.28	6.426 / 19.278 = 33.33%
2→3	3.213	4.92	1.53	3.213 / 12.852 = 25.00%
3→4	2.295	3.33	1.45	2.295 / 9.639 = 23.81%
4→5	0.918	0.74	0.81	0.918 / 7.344 = 12.50%

In the three stages from 1→2, 2→3, and 3→4, the improvement per unit area remains roughly stable (around 1.3–1.5 %/m²), indicating that the daylighting changes in these stages are primarily driven by the "amount of demolition"—in other words, larger demolition areas and higher ratios yield more significant effects while maintaining stable unit efficiency.

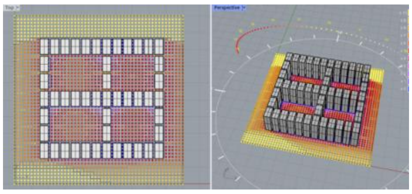
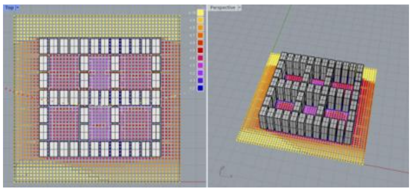
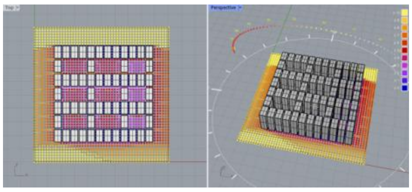
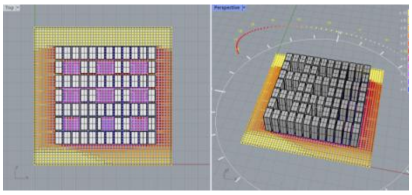
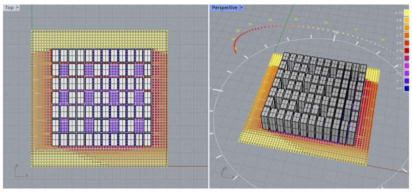
In the 4→5 stage, the unit efficiency drops noticeably (0.81 %/m²), and the relative demolition ratio in this step is only 12.5% (compared to ~24–33% in previous steps). This indicates that at such a small-scale demolition, the process has entered the diminishing returns zone: further small-scale removals hardly improve the daylighting environment. Therefore, demolishing up to step 3→4 already achieves most of the potential impact on daylight duration.

From this, it can be concluded that to achieve noticeable and cost-effective daylighting improvements, the demolition area must reach a relative threshold (approximately 20–30% in the current sample). Small-scale demolitions below ~12–13% generally do not produce meaningful daylighting enhancement.

(2) Courtyard-style demolition simulation of building clusters

Table4- 3Simulation Area Calculation of the Courtyard Demolition Method

Source: Author

Demolition Method	Demolition Simulation	Demolition Area(m²)	Non-Sunlight Ratio (Non-Sunlight Area/ Total Area)	Sunlight Ratio (1 – Non-Sunlight Ratio)
1		16.524	0.263055	0.736945
2		14.688	0.280063	0.719937
3		11.016	0.336088	0.663912
4		8.262	0.368835	0.631165
5		5.508	0.401699	0.598301

Based on the simulation in Table4- 3, the daylighting improvement efficiency and relative demolition ratios for the courtyard-style demolition method were calculated, as shown in Table4- 4.

Table4- 4Daylighting Efficiency of the Courtyard Demolition Method

Source: Author

Demolition Method	Demolition Simulation	Demolition Area	Non-Sunlight Ratio (Non-Sunlight Area ÷ Total Area)	Sunlight Ratio (1 – Non-Sunlight Ratio)
1→2	1.836	1.701%	0.926	11.11%

2→3	3.672	5.602%	1.526	25.00%
3→4	2.754	3.275%	1.189	25.00%
4→5	2.754	3.286%	1.193	33.33%

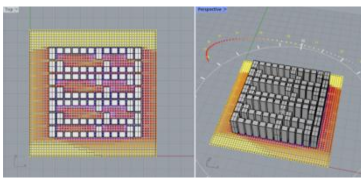
The unit return is highest for 2→3 (≈1.53 %/m²), indicating that when the courtyard is expanded to the scale of Scheme 3, each square meter of demolition yields the greatest daylight gain. The 1→2 step shows lower efficiency due to minimal demolition (only 11% relative removal), while the efficiency for 3→4/4→5 drops despite equal or higher relative demolition ratios, indicating diminishing returns for continued demolition (though still better than 1→2).

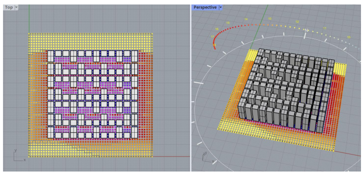
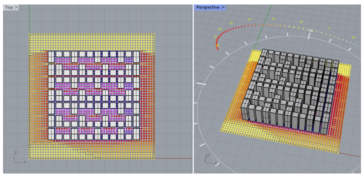
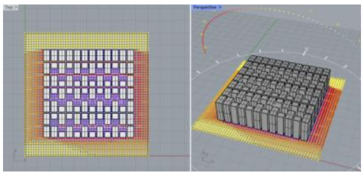
This demonstrates that, beyond the sheer area, the spatial configuration of the demolished portion is critical. Area or proportion serves only as a rough threshold; the actual daylighting outcome is determined by the spatial layout—i.e., which buildings are removed, what openings or courtyards are created, connectivity, orientation, and height differences. Removing key obstructing masses in central locations can significantly boost daylighting even with a small demolition area (high efficiency), whereas removing peripheral portions that minimally impact primary daylight directions provides limited improvement regardless of area. Moreover, compared with staggered demolition, the courtyard-style approach achieves better daylight enhancement.

(3) Scattered demolition simulation of building clusters

Table4- 5Simulated Area Calculation of the Scattered Demolition Method

Source: Author

Demolition Method	Demolition Simulation	Demolition Area(m²)	Non-Sunlight Ratio (Non-Sunlight Area / Total Area)	Sunlight Ratio (1 – Non-Sunlight Ratio)
1		12.852	0.301901	0.698099

2		11.016	0.323591	0.676409
3		9.639	0.344389	0.655611
4		6.885	0.374215	0.625785

Based on the simulation in Table4- 5, the calculated daylighting improvement efficiency and relative demolition ratios for the scattered demolition approach are presented in Table4- 6.

Table4- 6Daylighting Efficiency of the Scattered Demolition Method

Source: Author

Demolition Method	Demolition Simulation	Demolition Area	Non-Sunlight Ratio (Non-Sunlight Area ÷ Total Area)	Sunlight Ratio (1 – Non-Sunlight Ratio)
1→2	1.836	2.169	1.18	14.29%
2→3	1.377	2.080	1.51	12.50%
3→4	2.754	2.983	1.083	28.57%

1→2: Demolished 1.836 m², daylighting improvement 2.169%, unit-area improvement rate 1.18 %/m².

2→3: Demolished the least (1.377 m²), daylighting improvement 2.080%, unit-area improvement rate 1.51 %/m² → the highest efficiency across all stages.

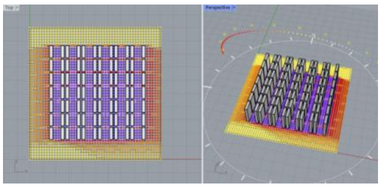
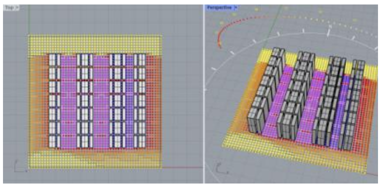
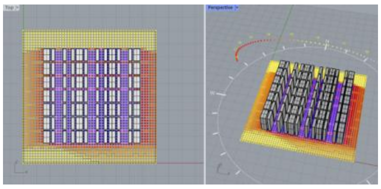
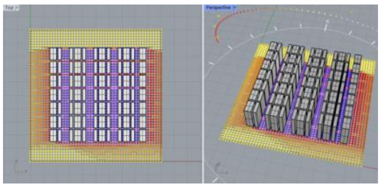
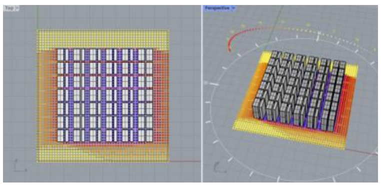
3→4: Demolished 2.754 m², daylighting improvement 2.983%, unit-area improvement rate 1.083 %/m².

From the table, the highest efficiency occurs in stage 2→3, where the demolition area is the smallest and the unit-area daylighting improvement rate is the largest (1.51 %/m²). This indicates that a relative demolition ratio of around 12.5% for scattered points in the site is sufficient. Compared with the 2→3 stage of courtyard demolition, which has a maximum unit return of ≈1.53 %/m² but a relative demolition ratio of 25.00%, the scattered demolition achieves nearly the same efficiency with half the relative demolition proportion, demonstrating that the scattered approach is more effective.

(4) Light-filled corridor demolition simulation of the building cluster

Table4- 7Simulated Area Calculation of the Light-filled Corridor Demolition Method

Source: Author

Demolition Method	Demolition Simulation	Demolition Area(m²)	Non-Sunlight Ratio (Non-Sunlight Area / Total Area)	Sunlight Ratio (1 – Non-Sunlight Ratio)
1		25.704	0.258836	0.741164
2		19.278	0.230936	0.769064
3		12.852	0.345066	0.654934
4		11.2455	0.362725	0.637275
5		8.0325	0.464594	0.535406

Based on the simulation inTable4- 7, the daylight corridor demolition strategy’s daylight improvement efficiency and relative demolition ratios were calculated, as shown in Table4- 8.

Table4- 8Daylighting Efficiency of tthe Light-filled Corridor Demolition Method

Source: Author

Demolition Method	Demolition Simulation	Demolition Area	Non-Sunlight Ratio (Non-Sunlight Area ÷ Total Area)	Sunlight Ratio (1 – Non-Sunlight Ratio)
1→2	6.426	-2.790	-0.434	25.00%
2→3	6.426	11.413	1.776	33.33%
3→4	1.6065	1.766	1.099	12.50%
4→5	3.213	10.187	3.172	28.57%

1→2: Demolished 6.426 m², daylight decreased (-2.79%), representing the lowest efficiency.

2→3: Demolished 6.426 m², daylight increased 11.413%, with a unit area improvement rate of 1.776 %/m².

3→4: Demolished 1.6065 m², daylight increased 1.766%, with a unit area improvement rate of 1.099 %/m².

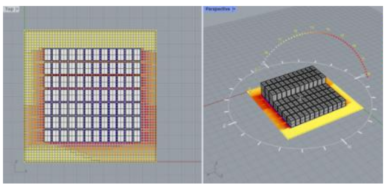
4→5: Demolished 3.213 m², daylight increased 10.187%, with a unit area improvement rate of 3.172 %/m² → the highest efficiency across all steps.

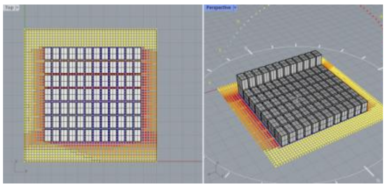
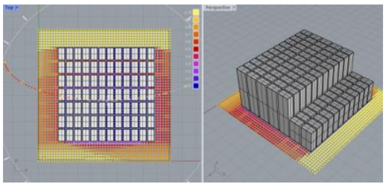
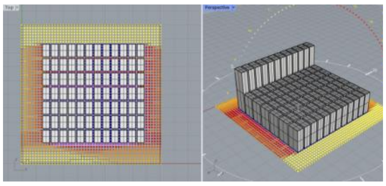
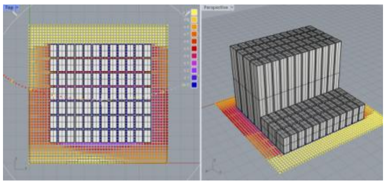
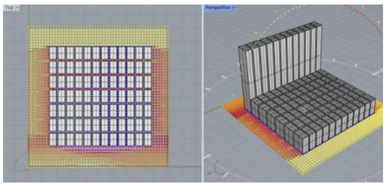
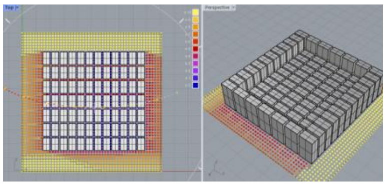
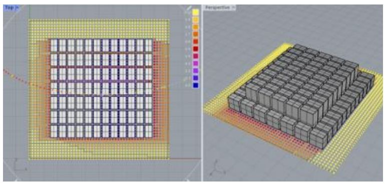
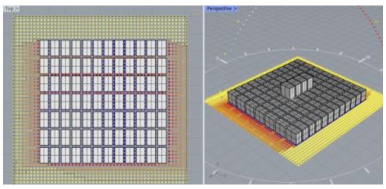
From this, it can be concluded that the unit efficiency fluctuates significantly between different steps (some steps have very high efficiency, others low, likely due to the width of the daylight corridors being more important than the number); certain increments can rapidly boost daylight, but the effect is unstable and requires large-scale demolition to achieve a substantial overall improvement.

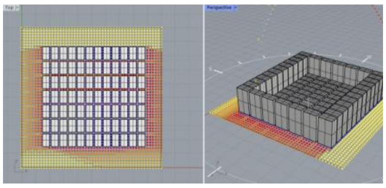
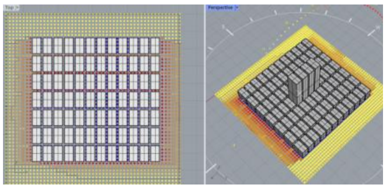
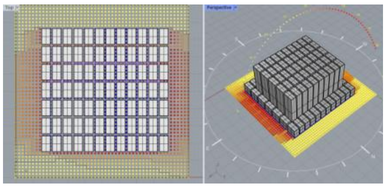
(5) Simulation of cluster demolition via height reduction strategy (here, "height reduction" refers to modifications achieved through reducing building height).

Table4- 9Simulated Area Calculation of the Height-Based Demolition Method

Source: Author

Demolition Method	Demolition Simulation	Demolition Area(m²)	Non-Sunlight Ratio (Non-Sunlight Area / Total Area)	Sunlight Ratio (1 – Non-Sunlight Ratio)
1		10.26	0.47032	0.529679

2		16.52	0.470479	0.529521
3		18.54	0.480184	0.519816
4		33.05	0.480186	0.519814
5		25.69	0.470257	0.529743
6		49.57	0.470372	0.529628
7		11.47	0.482562	0.517438
8		13.77	0.474556	0.525444
9		14.57	0.485675	0.514325

10		22.95	0.483748	0.516252
11		18.36	0.485741	0.514259
12		10.557	0.474585	0.525415

Based on the simulation in Table4- 9, the author calculated the daylight improvement efficiency and relative demolition ratios for different height-reduction strategies, as shown in Table4- 10.

Table4- 10Daylighting Efficiency of the Height-Based Demolition Method

Source: Author

Demolition Method	Demolition Simulation	Demolition Area	Non-Sunlight Ratio (Non-Sunlight Area ÷ Total Area)	Sunlight Ratio (1 – Non-Sunlight Ratio)
1→2	+6.26	−0.016	−0.003	0.610
2→3	+2.02	−0.971	−0.481	0.122
3→4	+14.51	−0.000	-0.000	0.783
4→5	−7.36	+0.993	−0.135	−0.223
5→6	+23.88	−0.012	−0.001	0.929
6→7	−38.10	−1.219	+0.032	−0.769
7→8	+2.30	+0.801	+0.348	0.201
8→9	+0.80	−1.112	−1.390	0.058
9→10	+8.38	−0.207	−0.025	0.575
10→11	−4.59	−0.199	+0.043	−0.200
11→12	−7.80	+1.115	−0.143	−0.425

From Table4- 9, the relationship between demolition areas at different heights and daylighting improvement efficiency is as follows:

First, using height reduction to enhance daylight provides limited overall improvement. Based on the non-daylit ratio (~0.47–0.49), the daylight ratio remains around 0.51, fluctuating less than 1%. This indicates that adjusting building height has minimal impact on overall daylight conditions; even large-scale height modifications result in negligible changes to illumination.

Second, height-based demolition shows large fluctuations in unit efficiency but remains generally low. Most steps have a unit efficiency (%/m²) close to 0 or even negative, meaning “even with significant demolition, improvements are minimal.” For example, in step 3→4, 14.51 m² (about 78% of the previous area) was demolished, yet daylight gain was zero, representing an inefficient or “wasted” intervention. In some cases, demolition even led to decreased daylight (e.g., steps 2→3, 8→9), demonstrating potential “adverse effects” from height adjustments alone.

Additionally, there are cases where more demolition leads to lower efficiency. For instance, in step 5→6, an additional 23.88 m² was removed, but daylight only improved by −0.012 percentage points, almost negligible. In step 6→7, less demolition paradoxically resulted in worse daylight, further highlighting efficiency volatility.

4.2.1.2. Comparative Simulation Results of Different Demolition Strategies for Prototype Cluster Spaces

Based on the premise of the "micro-regeneration" concept established in this study, this section discusses various demolition simulations. These simulations are conducted in scenarios where passive daylighting optimization has been implemented, yet the overall daylighting levels and spaces conducive to visual health activities remain insufficiently improved. Through the study of different demolition strategies, the aim is to identify methods that achieve minimal intervention while enhancing daylighting efficiency and promoting residents' health. The effectiveness of different demolition approaches is outlined as follows:

Intermittent Demolition: Unit efficiency remains generally high (some steps reaching ~1.3–1.5 %/m²), indicating that “moderate increases in demolition area in this layout can reliably yield high returns.”

Courtyard Demolition: Exhibits an optimal range (unit efficiency peaks at ~20–30% relative demolition), confirming the previously observed “threshold effect” — a certain proportion must be removed to form a connected courtyard for effective daylight gain.

Scattered Demolition: Compared to courtyard demolition, maximum unit returns are similar, but the relative demolition ratio is much lower, making scattered demolition more efficient and capable of significantly increasing daylight duration.

Light Corridor Demolition: The width of the light corridor is more influential than the number of corridors, causing large fluctuations in unit efficiency across different steps. Certain increments rapidly boost daylight, but large-scale demolition is needed to widen corridors and achieve overall improvement.

Height-Based Demolition: Daylight ratio remains around ~51%, fluctuating less than 1%. Even extensive height modifications barely improve daylight, indicating that daylight is mainly determined by the planar layout rather than height differences. Some areas are insensitive to height changes (e.g., edges or south-facing open zones) — even increasing building height does not significantly worsen daylight. In densely obstructed zones (e.g., narrow east–west streets, dense core areas), reducing height yields minimal daylight improvement. Therefore, selective height adjustments or partial demolition can be used to free up ground-level public space.

Summary of Overall Efficiency Ranking for Public Space Daylight by Demolition Strategy: Scattered Demolition > Courtyard Demolition > Intermittent Demolition > Light Corridor Demolition > Height-Based Demolition.

4.2.2. Daylight Optimization and Simulation for Street and Alley Prototype Spaces

4.2.2.1. Daylight Issues in Street and Alley Prototype Spaces

The street and alley spaces in Shipai Village exhibit significant light-health problems. On one hand, narrow openings at the top of the alleys severely limit natural light penetration, resulting in insufficient overall illumination. Ground-floor and lower- to mid-level rooms along the streets experience persistently low illuminance, with minimum levels of only 2–50 lx under cloudy conditions, and even sunny days fail to provide consistently adequate daylight. This impacts residents' daytime activity rhythms and psychological comfort. On the other hand, daylight quality is uneven, particularly in the vertical direction: upper floors on both sides may receive excessive light, while mid- and lower-level rooms and street-level public spaces suffer from insufficient illumination. Residents and street users often rely on artificial lighting, which not only increases energy consumption but also reduces visual comfort and may compromise safety due to dim conditions. In summary, extending natural light exposure duration and improving ground-level illuminance are key objectives for enhancing light-health in street and alley spaces.

4.2.2.2. Strategies for Optimizing Daylight in Street and Alley Spaces

To address insufficient daylight in Shipai Village's residential units and street spaces, traditional solutions typically involve two approaches. The first is installing artificial lighting in underlit areas; however, this does not fulfill residents' physiological and psychological needs for natural light and significantly increases building energy consumption, conflicting with energy-saving goals. The second is using light tubes or similar technologies to guide sunlight through highly reflective channels into deep interior or underground spaces, as shown in Figure4- 6. However, light tubes primarily provide point-to-point indoor lighting, require additional piping systems, and incur high installation and maintenance costs, failing to solve multi-point illuminance issues.

Given the extremely narrow spacing between buildings in Shipai Village, "light-guiding spaces" naturally form. By combining the principles of light tubes with the spatial configuration, reflective materials can be applied to alley walls so that sunlight is repeatedly reflected along walls and alley floors. This approach effectively guides daylight deeper into the space, reducing reliance on artificial lighting.

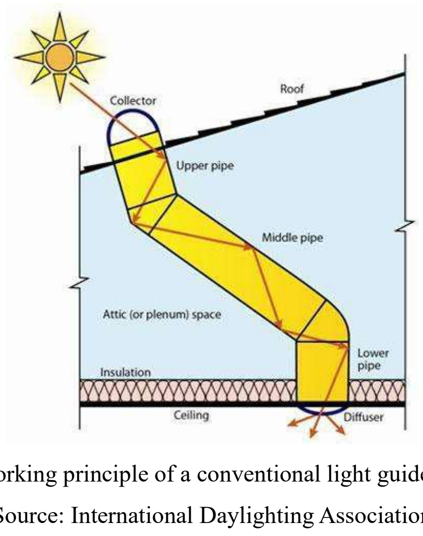


Figure4- 6Working principle of a conventional light guide tube system

Source: International Daylighting Association

Therefore, drawing on the principles of traditional light tube and the 2024 International VELUX competition proposals for daylight improvements in urban villages(Figure4- 7), the author designed a daylighting component suitable for narrow alley(Figure4- 8), consisting of three main parts, as shown in Figure4- 9:

Top: A light collector is installed at the top, inspired by the light-collection section of a light tube. The point-shaped collector is designed as a linear structure to guide more natural light into the street and alley.

Middle: Narrow slits are converted into light-guiding channels. By applying high-reflectance materials to the alley walls, sunlight is reflected from the top down to the bottom.

Bottom: For ground-level commercial spaces, a diffuse reflection device is installed at the location of the awnings. The awnings are inverted while retaining their shading function, and the concave surfaces are lined with high-reflectance materials to scatter light evenly to the street level.

This design fills the alley with sunlight, improves ground-floor illuminance, and achieves a light-health-oriented renovation of street and alley spaces.

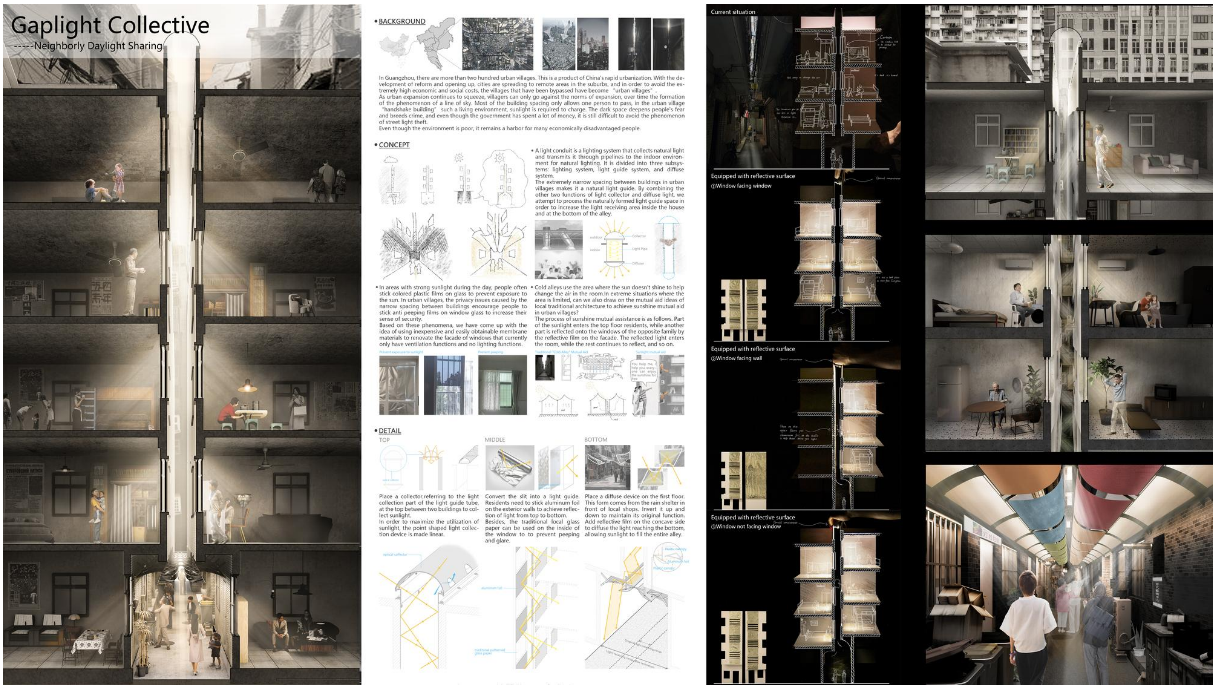


Figure4- 7 Winning Projects of the 2024 International VELUX Award

Source: ArchDaily

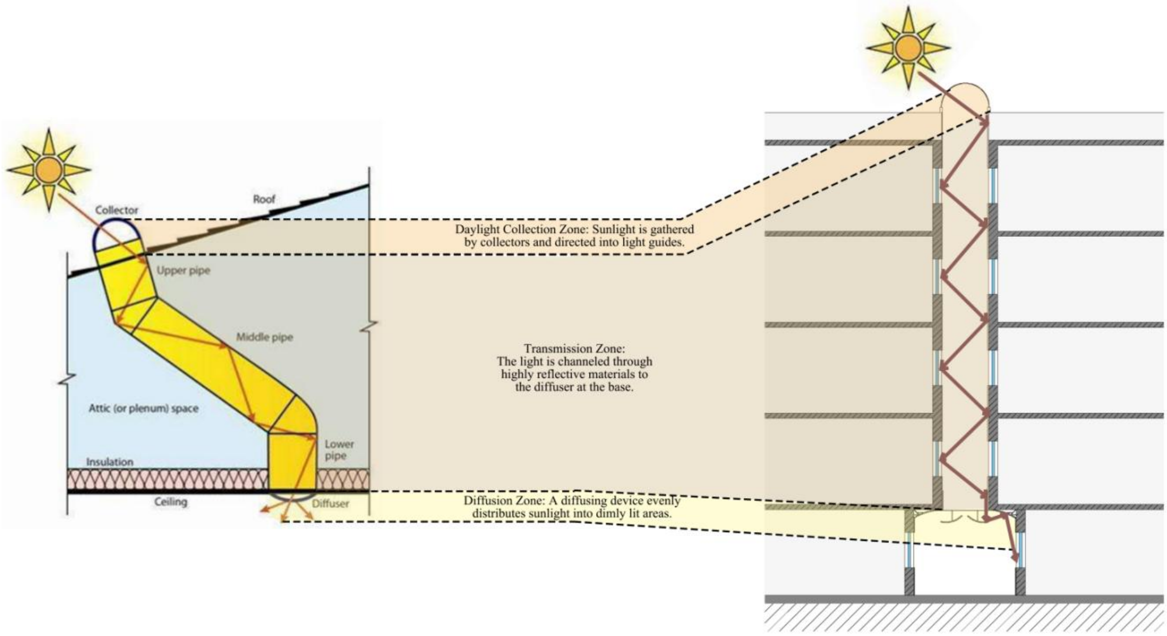


Figure4- 8Integrating light guide tube principles in street and narrow alley

Source: Author

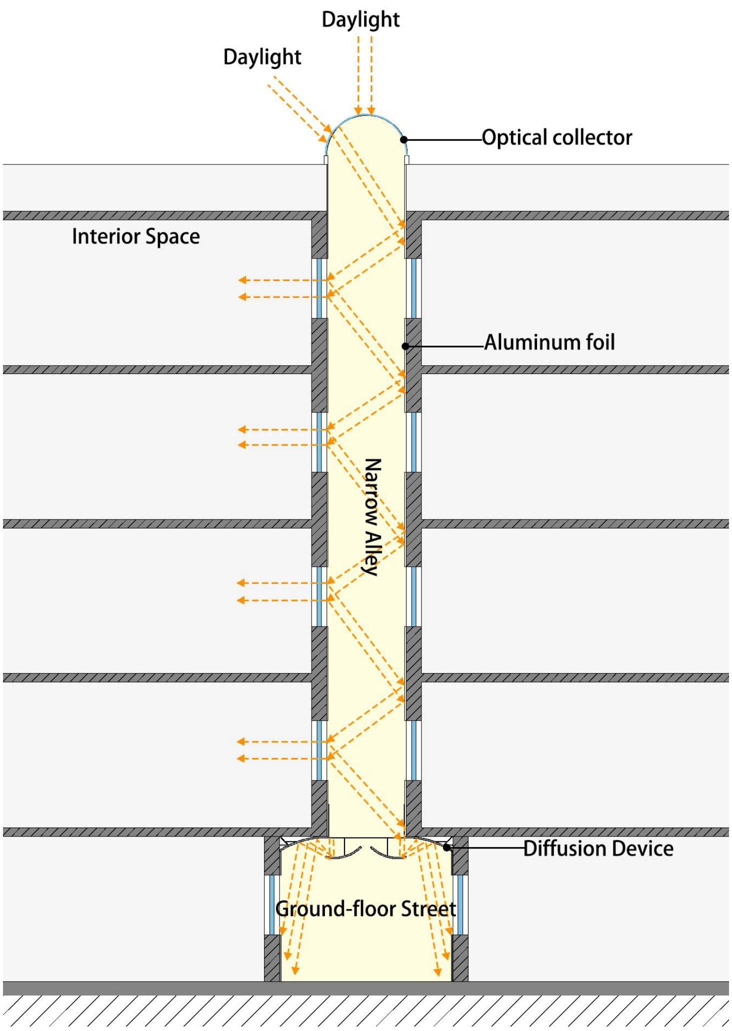


Figure4- 9Schematic Diagram of Daylight Guiding Optimization in Streets and Alleys

Source: Author

4.2.2.3. Simulation of Street and Alley Space Light Health under Different Renovation Measures

(1) Analysis of Results with Different Wall Coating Materials

After establishing the street and alley space prototype, simulations were conducted using the VELUX Daylight Visualizer to assess changes in ground-level illuminance under different materials, as shown in Figure4- 10.

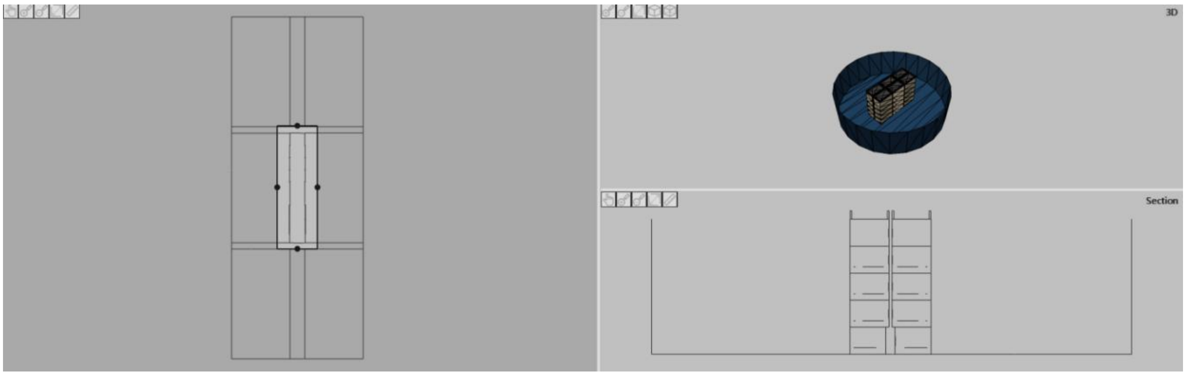


Figure4- 10VELUX Daylight Visualizer Software Simulation Interface

Source: Author

First, 50%-reflectance plastic panels were applied to both sides of the street and alley walls, as shown in Figure4- 11, and the resulting street illuminance simulation is presented in Table4- 11.

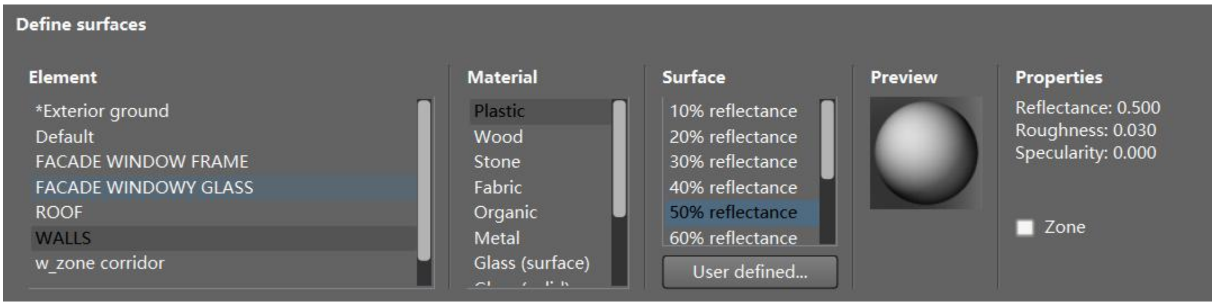


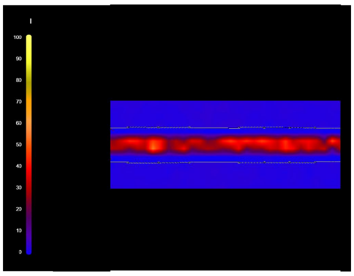
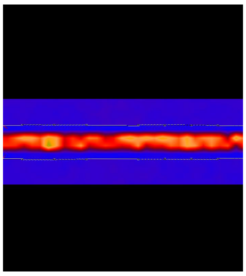
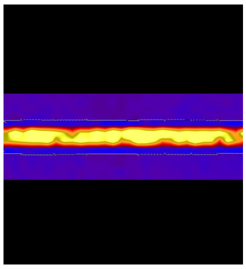
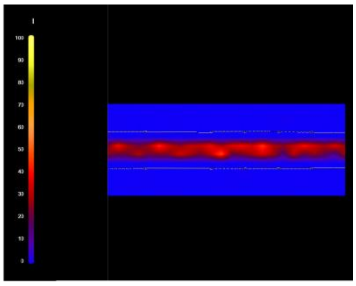
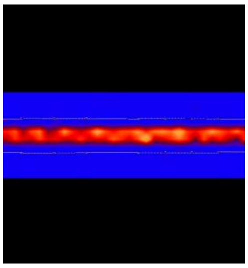
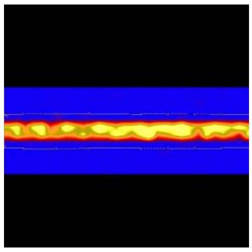
Figure4- 11VELUX Daylight Visualizer Material Modification Interface

Source: Author

Table4- 11Simulation Result of Plastic with 50% Reflectance

Source: Author

	Simulation Plane Height: 1210 mm	Simulation Plane Height: 5210 mm	Simulation Plane Height: 9210 mm

Original			
Plastic			

Next, high-reflectance aluminum panels were applied to both sides of the street and alley walls, as shown in Figure4- 12, and the resulting street illuminance simulation is presented in Table4- 12.

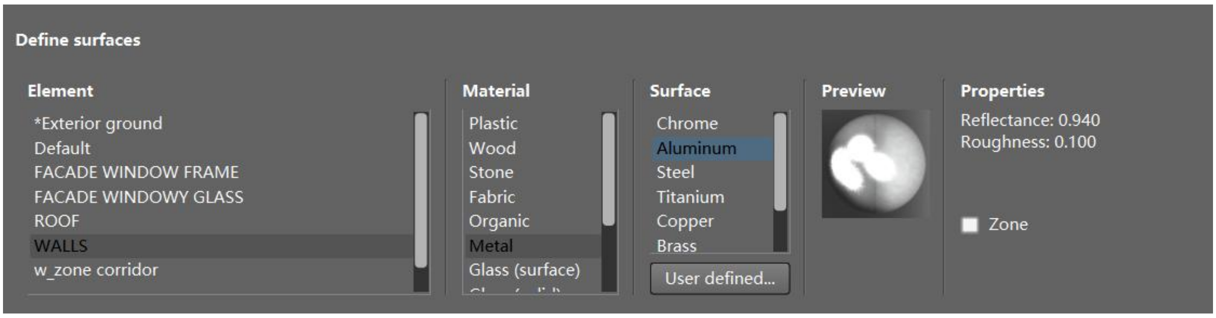
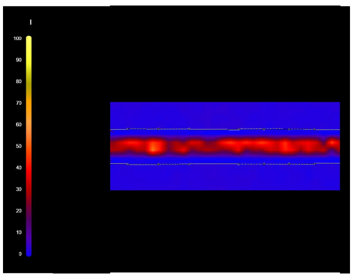
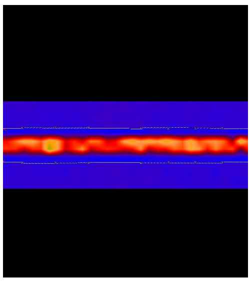
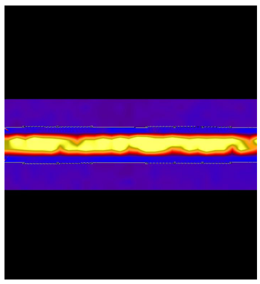


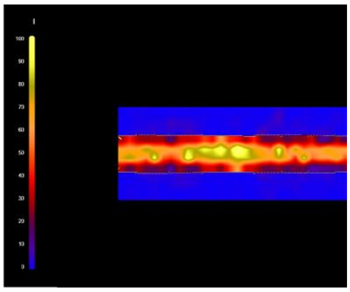
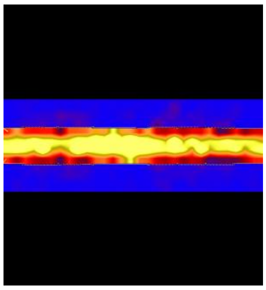
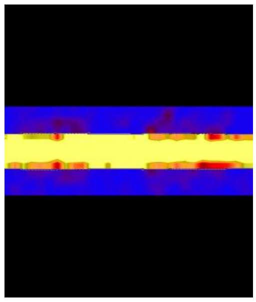
Figure4- 12VELUX Daylight Visualizer Material Editing Interface

Source: Author

Table4- 12Simulation Result of Metal Aluminum with 94% Reflectance Coefficient

Source: Author

	Simulation Plane Height: 1210 mm	Simulation Plane Height: 5210 mm	Simulation Plane Height: 9210 mm
Original			

Aluminum			

This indicates that applying high-reflectance materials to the walls on both sides of the street and alley helps increase the diffuse reflection of natural light from above, enhancing illuminance at the street level, which is consistent with theoretical expectations.

(1) Analysis of Results for Different Light-Guiding Component Designs

After establishing the street and alley space prototype in the previous step, light-guiding components were added to the alley gaps to observe their effect on increasing illuminance at the street level, as shown in Figure4- 13 and Figure4- 14.

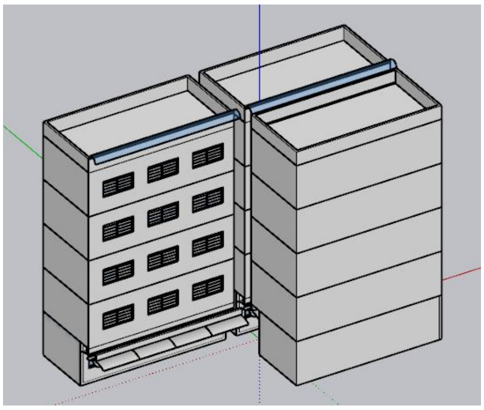


Figure4- 13Light-Guiding Structure and Street Model

Source: Author

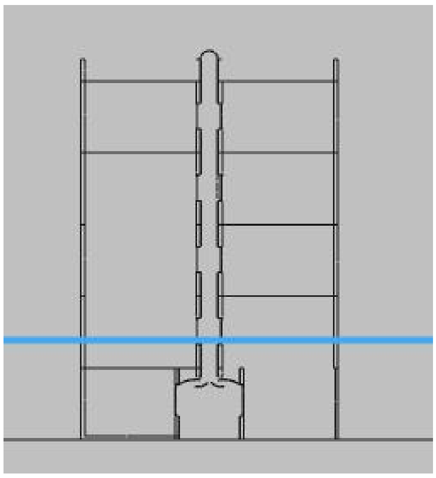


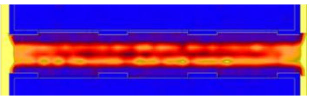
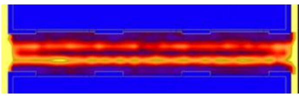
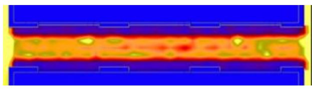
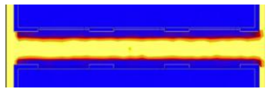
Figure4- 14Section of Light-Guiding Component Model

Source: Author

The angle, length, and height of the light-guiding components were adjusted, as shown in Table4- 13, to determine the optimal light-guide panel angle for 12:00 noon on March 21.

Table4- 13Simulation Results of Light-Guiding Component Adjustment

Source: Author

Add Component	Increase Reflector Length	Adjust Reflector Height	Adjust Reflector Angle
			

Furthermore, the street lighting conditions for different months were simulated. Table4- 14 compares the simulation results for March and April, and Figure4- 15 identifies the month with the best improvement effect.

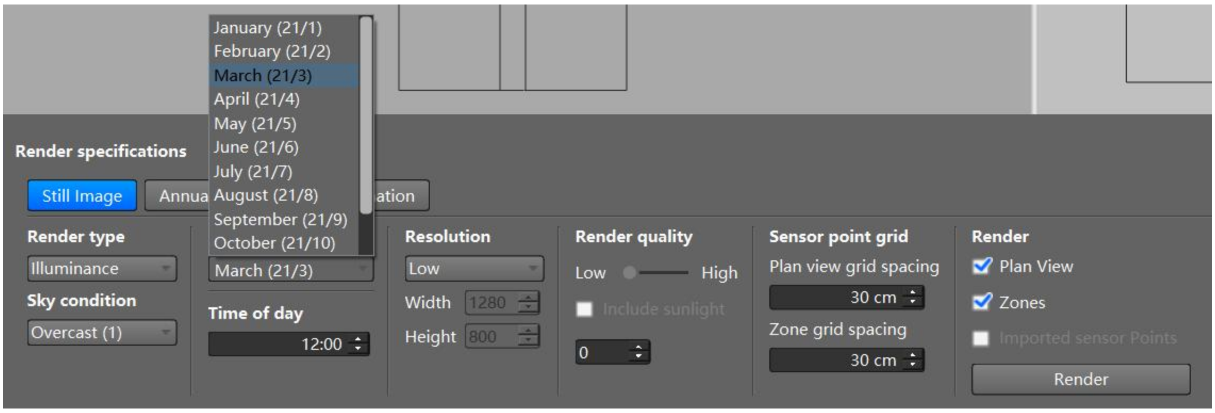
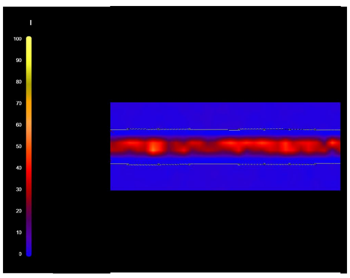
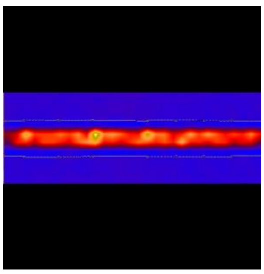
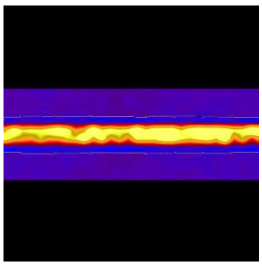


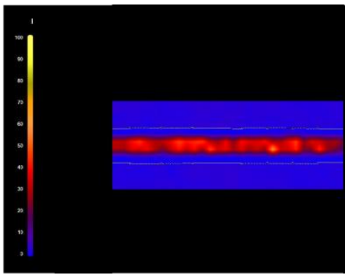
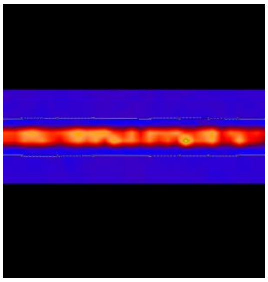
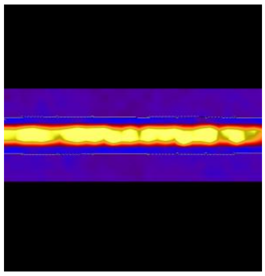
Figure4- 15VELUX Daylight Visualizer Simulation Adjustment Results

Source: Author

Table4- 14Simulation Results for March and April

Source: Author

	Simulation Plane Height: 1210 mm	Simulation Plane Height: 5210 mm	Simulation Plane Height: 9210 mm
March			

April			

By adjusting the angle and height of the light-guiding panels, the optimal outdoor illuminance condition can be achieved. Simulations conducted from January to December indicate that under the panel adjustments, April 21st—with its solar altitude—yields the best improvement effect.

4.3. Indoor Prototype Space Simulation and Optimization

4.3.1. Indoor Prototype Space Light-Health Issues and Simulation Optimization

4.3.1.1. Light-Health Issues in Indoor Prototype Spaces

The light-health issues in typical residential units of Shipai Village are mainly reflected in the following aspects: First, insufficient horizontal illuminance. Units on lower floors with unfavorable orientation have an average daily illuminance of only 80–90 lx, far below the 300–500 lx required for visual comfort in light-health standards, and inadequate for the higher illuminance needs of elderly residents or study areas (≥300–750 lx). The daylight factor (DF) is also low, failing to meet health standards (≥2.5%). Regarding morning high-illuminance exposure requirements, lower- and mid-floor rooms receive insufficient morning light, making it difficult to achieve ≥30 minutes of exposure at ≥1000 lx, which affects residents' circadian rhythms. In terms of indoor illuminance uniformity, although the overall uniformity exceeds 0.87, the rectangular unit layouts with windows concentrated on one side make it difficult for natural light to reach deeper areas, creating dark zones at commonly used work surfaces like desks, thereby impacting daily activities.

4.3.1.2. Simulation and Analysis of Indoor Light-Health under Different Retrofit Measures

Where the limited penetration of natural light into interior spaces persists, a light well was inserted within the unit, representing a scatter-type retrofit. This approach allows well-lit areas to penetrate into poorly lit areas, improving overall Light Health. The residential unit prototype was retrofitted with light wells, with pre- and post-retrofit floor plans shown in Figure4- 16 and Figure4- 17, and the resulting indoor illuminance improvements summarized in Table4- 15.

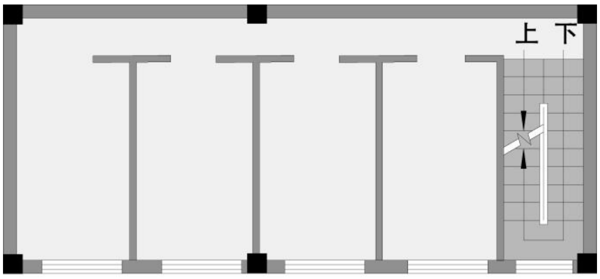


Figure4- 16Residential Unit Pre-Renovation Diagram

Source: Author

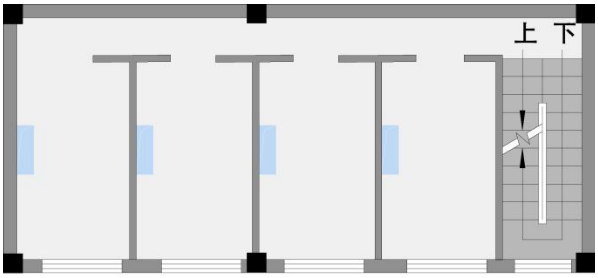
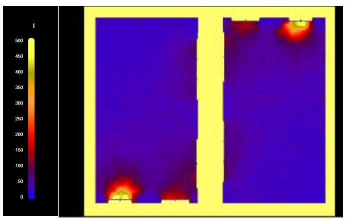
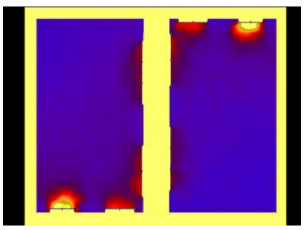
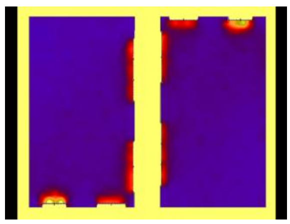
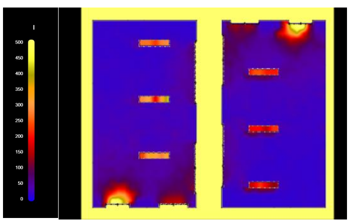
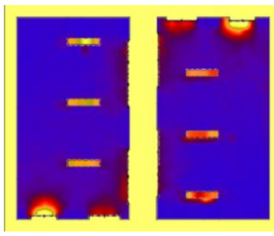
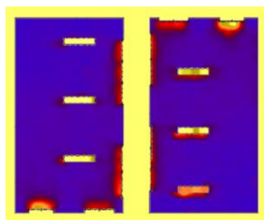


Figure4- 17Residential Unit Post-Renovation Diagram

Source: Author

Table4- 15The Enhancement of Indoor Daylighting through the Insertion of a “Light Well”

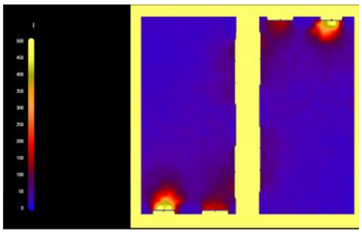
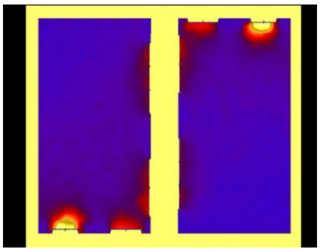
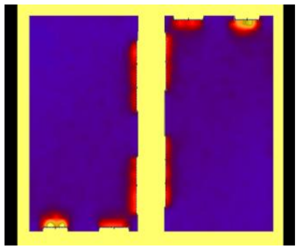
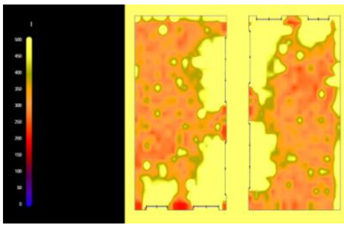
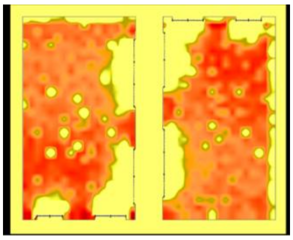
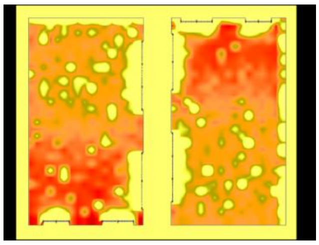
Source: Author

	Simulation Plane Height: 1210 mm	Simulation Plane Height: 5210 mm	Simulation Plane Height: 9210 mm
Original			
Aluminum			

In addition to installing “light wells” indoors, indoor illuminance can also be enhanced by introducing natural daylight from the streets. Table4- 16 below shows the changes in indoor daylight achieved by applying aluminum foil to the windows.

Table4- 16The Enhancement of Indoor Daylighting through Aluminum Foil

Source: Author

	Simulation Plane Height: 1210 mm	Simulation Plane Height: 5210 mm	Simulation Plane Height: 9210 mm
Original			
Aluminum			

4.4. Chapter Summary

This chapter takes Shipai Village in Guangzhou as a case study, establishing models of individual buildings and building clusters to simulate daylight hours. First, through comparative simulations of various regeneration approaches—including interval-type, courtyard-type, scattered-type, light-corridor-type, and height-based demolitions—it explores how to achieve an optimal balance between demolition area and daylight efficiency when demolition becomes unavoidable. Second, based on field surveys, spatial prototypes of street lanes and residential units are summarized, identifying core issues such as inadequate natural daylight at the ground level and poor uniformity of indoor illumination, resulting from high building density, narrow alleyways, and deep-plan building layouts. In response, a prototype intervention is proposed, which involves integrating light-guiding elements into the streets and applying high-reflectivity materials on both side walls to enhance illuminance at the bottom level. Finally, for the renovation of individual buildings, internal daylight conditions are improved by introducing "light wells" and optimizing window glazing materials. Together, these measures form integrated daylight health renewal strategies across four scales: overall, street, node, and building unit, providing a theoretical foundation and practical reference for subsequent specific design strategies in Shipai Village.

Chapter5. DayLight Health Renovation and Performance Evaluation: A Case Study of Shipai Village

5.1. DayLight Health Renewal Strategies for Shipai Village

5.1.1. Existing Conditions Analysis of Shipai Village

The surrounding traffic network of Shipai Village is hierarchically structured and functionally clear. As shown in Figure5- 1, the main roads are Tianhe Road to the north and Huangpu Avenue West to the south, both with high traffic volumes. Secondary main roads include Shipai East Road to the east and Shipai West Road to the west, which connect closely with the internal roads of Shipai Village and link to the main roads. The internal roads within Shipai Village are primarily pedestrian pathways; however, field surveys indicate that they are often shared by pedestrians and electric vehicles, creating issues with poor lighting and mixed traffic, which pose safety risks for pedestrians. Overall, the surrounding road network of Shipai Village is relatively complete and hierarchically clear, but attention must be paid to pedestrian-vehicle mixing and insufficient lighting within the village, which affect safety.

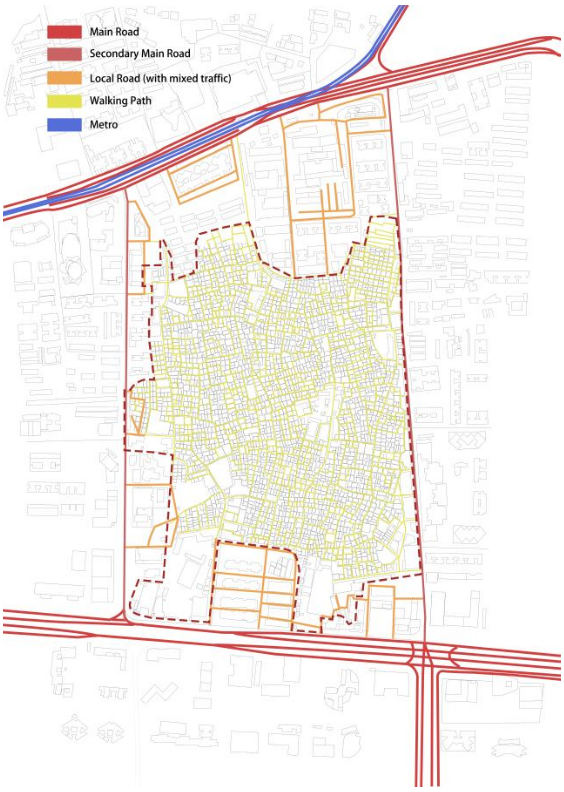


Figure5- 1Transportation Analysis around Shipai Village

Source: Author

The surrounding buildings of Shipai Village exhibit a pronounced contrast in height and gradient. As shown in Figure5- 2, the peripheral areas are dominated by high-rise buildings, forming the city skyline. In contrast, the interior of Shipai Village, as illustrated in Figure5- 3, is mainly composed of mid-rise and low-rise structures, which are relatively low and densely packed, mostly self-built residential units. This creates a stark contrast in building heights compared to the surrounding non–self-built structures, highlighting a distinctive urban form that has emerged within rapidly developing cities. The village displays a "high on the periphery, low in the interior" pattern, which must be considered in dayLight Health renovation strategies.

Figure5- 2Building Heights around Shipai Village

Source: Author

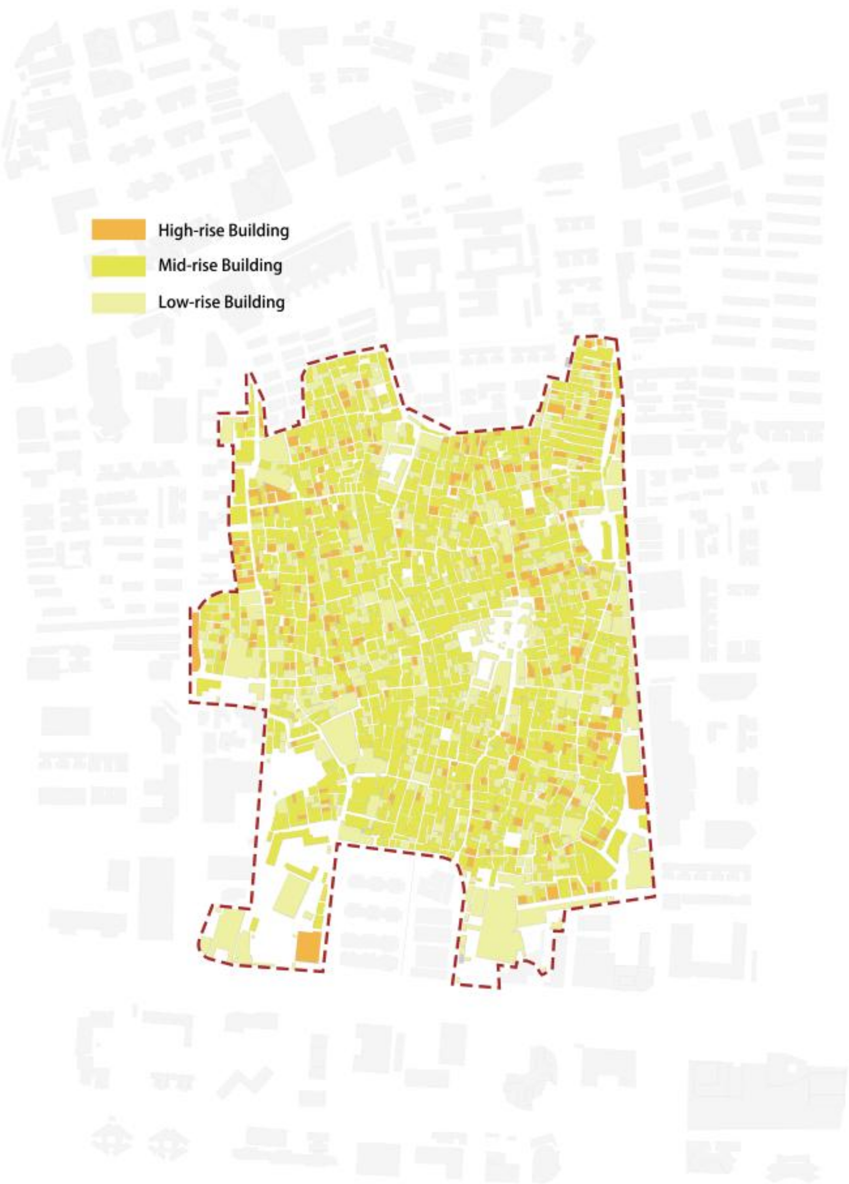


Figure5- 3Building Heights in Shipai Village

Source: Author

The functional distribution of buildings in and around Shipai Village exhibits noticeable differences. As shown in Figure5- 4, the surrounding areas are dominated by educational, cultural, medical, commercial, and residential buildings, providing relatively complete urban services that meet residents' basic needs for work, health, and consumption. In contrast, the internal functions of Shipai Village are more closely tied to daily life. As illustrated in Figure5- 5, besides residential, commercial, and educational/cultural buildings, there is a high concentration of dining establishments and a few ancestral halls. The dense presence of dining facilities reflects the active economic character and everyday life orientation within the village, while the ancestral halls serve as spaces of clan culture, carrying historical and collective memory for the community.

Figure5- 4Functional Analysis of the Surrounding Area of Shipai Village

Source: Author

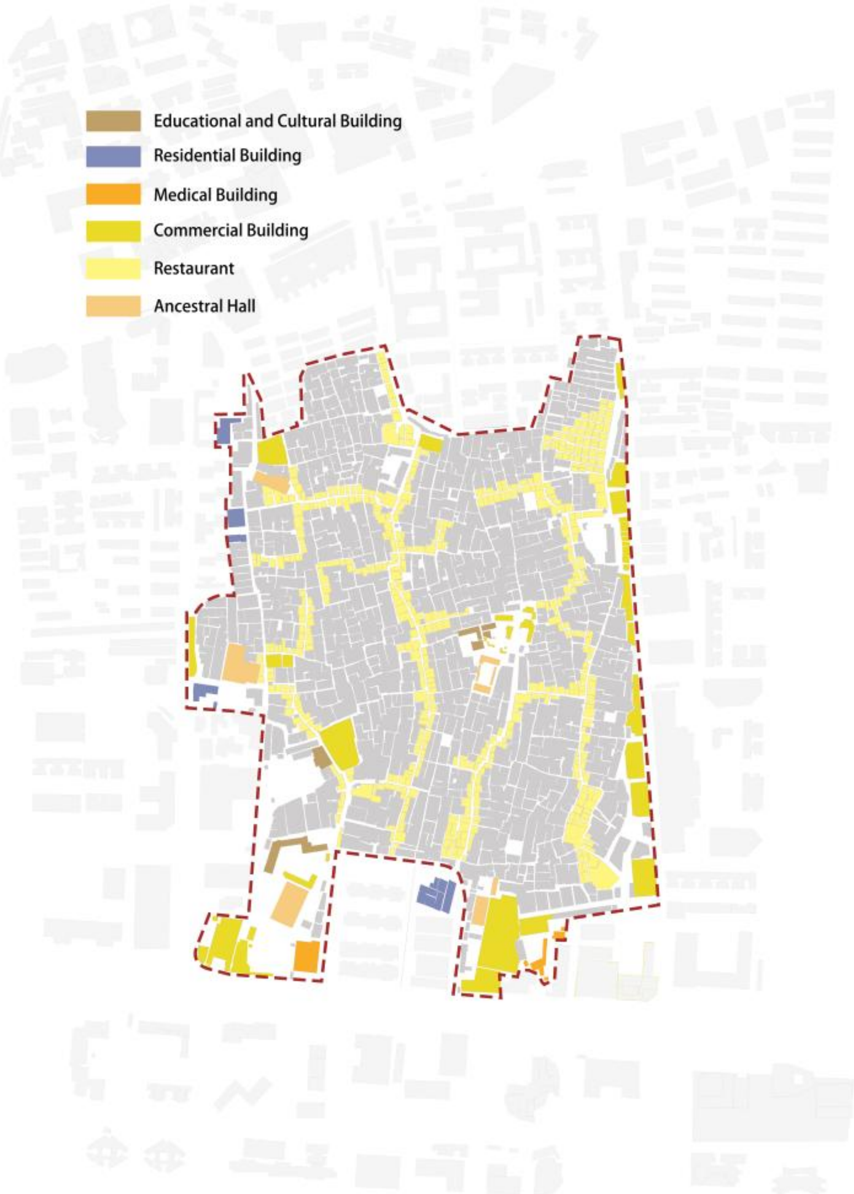


Figure5- 5Functional Analysis of the Interior of Shipai Village

Source: Author

As shown in Figure5- 6, Shipai Village has limited public spaces, lacking large centralized areas. Only a few scattered plazas or gathering points exist, including the ancestral hall plaza and school plaza, along with a small portion of water features, while large green spaces are almost nonexistent. Residents' recreational and activity spaces are therefore restricted, and most activities occur in areas with poor Light Health conditions. Street and alley spaces can also serve as a special type of public space, functioning as a composite of daily interactions, commerce, and leisure, combining both circulation and social functions. However, due to their narrow form, the spatial quality is poor.

Figure5- 6Analysis of Public Spaces in Shipai Village

Source: Author

As shown in Figure5- 7, the overall building quality in Shipai Village is predominantly medium or above. Protected buildings, such as ancestral halls and other traditional structures with historical and cultural value, are maintained and renovated rather than demolished. Buildings in excellent or good condition show signs of maintenance, are generally safe, and have relatively complete facilities; their Light Health levels can be enhanced through minor retrofits using high-reflectance materials. Buildings classified as "fair" exhibit some aging and outdated facilities, and partial demolition can be applied to improve Light Health. Buildings in "poor" condition are currently abandoned and may pose safety hazards; these can be demolished to create "sunlight nodes," forming areas with high-quality sunlight exposure for resident activities.

In summary, the overall building quality in Shipai Village is acceptable, making large-scale demolition inappropriate. A graded retrofit approach can be used to enhance the overall Light Health of the area.

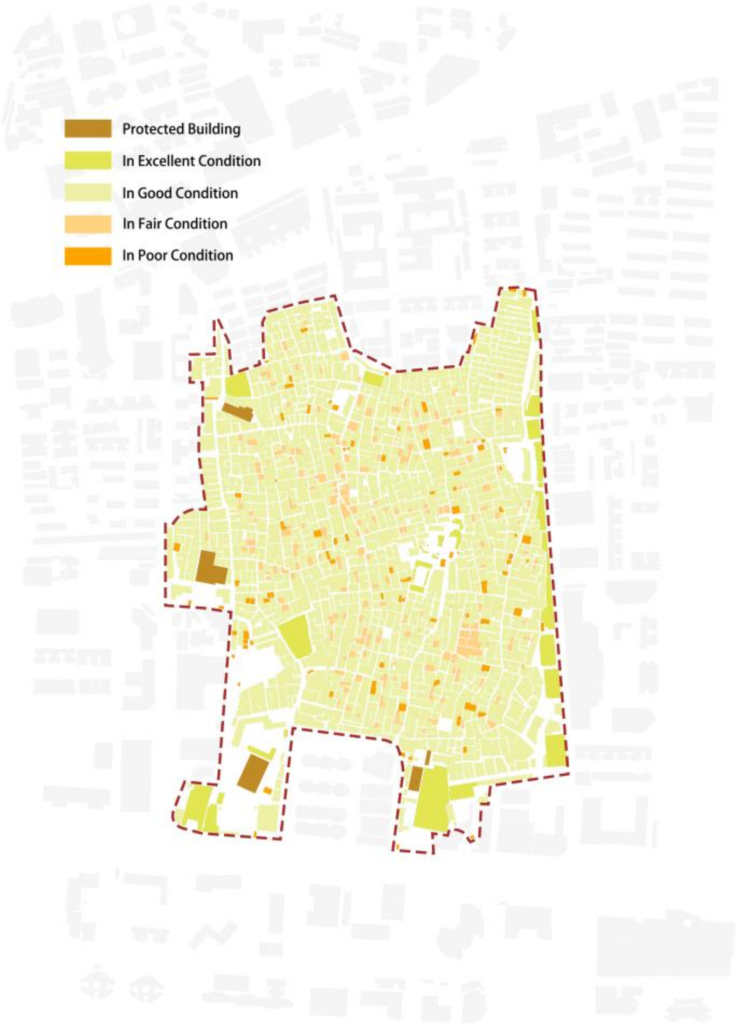


Figure5- 7Analysis of Building Quality in Shipai Village

Source: Author

As shown in Figure5- 8 and Figure5- 9, the overall sunlight conditions in Shipai Village are poor, exhibiting the typical characteristics of a high-density urban village. The vast majority of areas receive limited sunlight, particularly at the ground-floor level, in narrow street corridors, and within densely packed building clusters, where daily sunlight exposure is less than one hour, significantly affecting daylighting and comfort. Areas with relatively better sunlight are concentrated in a few open spaces, such as the ancestral hall plaza, school grounds, and water features. These areas, being free from building obstruction, can receive over five hours or more of sunlight and also serve as social spaces for residents' daily activities. Additionally, upper floors of taller buildings, not shaded by neighboring structures, may enjoy relatively good sunlight conditions.

Overall, Shipai Village's dense building layout and narrow spacing severely restrict sunlight penetration into interior spaces,as shown in Figure5- 8. In future redevelopment, in addition to the currently well-lit public areas, other areas should undergo interventions such as optimizing building density and layout, and adding public open spaces, in order to increase sunlight exposure and improve overall Light Health.

Figure5- 8Analysis of Sunshine Duration in Shipai Village on the Summer Solstice (June 22)

Source: Author

Figure5- 9 Section A-A~D-D: Existing Daylighting Conditions

Source: Author

Based on the comprehensive analysis of Shipai Village's transportation, building heights, functions, public spaces, building quality, and sunlight exposure, the spatial renovation potential of its buildings is mapped in Figure5- 10. The classification is determined as follows:High-potential buildings—those abandoned, structurally poor, under two stories, with small floor areas, low demolition costs, and zero sunlight exposure — can significantly improve surrounding light health through renovation. Medium-potential buildings, usually located near high-potential ones, have two or more stories, moderate quality and floor area, and over one hour of sunlight. They offer reasonable optimization space to moderately enhance light health conditions. Low-potential buildings receive over two hours of sunlight, are taller, in good condition, or worth preserving. Demolishing them is inefficient for improving daylight, so no or minimal intervention is recommended.

Overall, spatial redevelopment in Shipai Village should implement differentiated light environment optimization strategies according to potential levels. High-potential areas should be prioritized for light-health improvements, while the degree of intervention for low-potential buildings can be lower, with targeted measures corresponding to the renovation potential of each building.

Figure5- 10Potential for Spatial Renovation in Shipai Village

Source: Author

5.1.2. Summary of Shipai Village Renovation Strategies

Based on the current conditions of Shipai Village and typical spatial optimization approaches, renovation strategies tailored to this specific site are proposed. These strategies address the needs of different user groups and design interventions, and are organized into the following four levels for the renovation of Shipai Village (Table5- 1,Table5- 2):

Table5- 1Design Levels and Light Health Issues

Source: Author

Indoor/Outdoor	Light-Health Dimension	Corresponding Behaviors & Issues
Overall Level	Physiological Impact	1. Sunbathing, exercising, chatting (Huang Grandma, Zhang Uncle, Xiao Cai, Xiao Jing) 2. Very few public spaces (only 3), limited space, dark streets hinder walking 3. Lack of sunny green spaces, leading to reduced physical activity
	Psychological Impact	1. Children playing, elderly playing chess or dancing (Huang Grandma, Xiao Cai, Xiao Jing) 2. Limited light in activity areas, unable to meet needs of all age groups
Street & Alley Level	Physiological Impact	1. Cooking, living, working/studying (Sister Huang, Mr. Huang, Mr. Liu, Xiao Deng, Mr. Wang) 2. Dark streets, severe building shading, poor daylight at ground level
	Psychological Impact	1. Low willingness to stay out/socialize at home (Xiao Deng, Sister Huang, Mr. Liu, Mr. Wang) 2. Narrow, dark streets suppress social interaction, lack reasons to leave home
Individual Unit Level	Physiological Impact	1. Cooking, living, working/studying (young residents, shop workers) 2. Deep interior spaces, kitchens/desks located away from windows, ground floors rely on artificial lighting year-round 3. Rooftop spaces underutilized, mainly for drying clothes and privatized, lacking public use
	Psychological Impact	Young residents at home experience low mood in dim environments, leading to reduced social interaction

Table5- 2Shipai Village Multi-level Renovation Strategies

Source: Author

Level of Intervention	Current Light-Health Issues in Shipai Village	Light-Health Upgrade Strategies for Shipai Village	Corresponding Light-Health Indicators
Overall Level	1. Dense building layout with narrow spacing, insufficient ground-level daylight; most areas receive less than 1 hour of sunlight. 2. Buildings are generally mid- to low-rise, few	1. Assess building quality, function, and height to delineate intervention potential zones. 2. Implement scattered, courtyard, interval, and light-corridor demolition	Outdoor: Natural light exposure duration (>2h, >1000 lx) Ground-level illuminance (≥100 lx)

	high-illuminance floors. 3. Some low-quality buildings pose safety risks and cast shadows on surrounding structures. 4. Limited public space; residents' activities mostly occur in poorly lit areas.	strategies to improve overall natural lighting. 3. Streamline the existing road network and define intervention levels for each area to provide a foundation for subsequent upgrades.	
Street & Alley Level	1. Poor daylight at street-level in main streets; pedestrian and e-bike mixed traffic compromises safety. 2. Secondary streets are generally narrow; ground-level sunlight <1h, local illuminance <20 lx; uneven light distribution creates shadowed areas, affecting safety and comfort.	1. Increase public activity spaces and green areas along main streets and open areas; provide street resting points to promote neighborhood interaction. 2. Install light-guiding elements on narrow secondary streets and apply high-reflectance materials on street walls to enhance ground-level light-health conditions.	Outdoor: Natural light exposure duration (>2h, >1000 lx) Ground-level illuminance (≥100 lx)
Node Level	1. Existing plazas are mostly scattered or associated with ancestral halls; limited public activity space. 2. Sunlit rooftop spaces are underutilized, lacking shared activity functions.	1. Transform selected areas into sunlit nodes; construct small plazas/micro-green spaces with good lighting. 2. Develop shared rooftop gardens, drying areas, resting zones, and small social spaces. 3. Add connecting corridors between buildings to improve accessibility and neighborhood interaction.	Outdoor: Natural light exposure duration (>2h, >1000 lx)
Individual Level	1. Insufficient indoor daylight; floor plans mostly rectangular, with deep interiors receiving poor light; uneven illumination distribution.	1. Introduce indoor light wells to bring rooftop daylight inside; apply high-reflectance materials to windows to channel street daylight indoors. 2. Design upper floors as public levels for exercise, walking, and shared functions to guide residents toward a light-healthy lifestyle.	Indoor: Horizontal illuminance (≥500–750 lx for work areas) Morning high illuminance (≥1000 lx) Daylight factor (DF ≥2.5%) Illuminance uniformity (Uo ≥0.7)

5.2. Light-Health Renovation Design for Shipai Village

5.2.1. Overall Renovation

Based on the "micro-regeneration" approach established as the core renovation concept, the author first conducted a comprehensive review of the existing road network system, as shown in Figure5- 11. While preserving the original spatial texture of the village, the structure of the main roads and secondary streets was maintained, and illegal extensions on both sides of the streets were removed. This resulted in a complete, continuous, and hierarchically clear road network, enhancing the overall connectivity and vitality of Shipai Village. This renovation not only addresses the current pedestrian–vehicle mixed traffic issue but also improves daylight conditions along the main road network, providing a foundation for subsequent secondary network renovations and the delineation of intervention zones.

Figure5- 11Road Network Organization

Source: Author

Next, based on the reorganized street network, the site was divided into multiple regeneration zones, as shown in Figure5- 12, with tailored graded intervention strategies developed according to the characteristics of each block. Buildings identified for preservation were protected; areas requiring refurbishment underwent scattered demolition to enhance natural daylight penetration. In key intervention zones—where passive retrofitting measures remained insufficient to meet Light Health requirements—courtyard-style, interval-style, and light-corridor-style demolition methods were flexibly applied. These approaches not only significantly improved ambient Light Health conditions but also created open spaces that provide residents with diverse public activity areas, establishing a spatial foundation for fostering a light-healthy lifestyle.The overall site plan and aerial renderings are presented in Figure5-13 and Figure5- 14, an exploded diagram is provided in Figure5- 15, and the functional distribution is illustrated in Figure5- 16. Aerial perspectives and schematic street views integrating light-guiding devices are shown in Figure5- 17 and Figure5- 18.

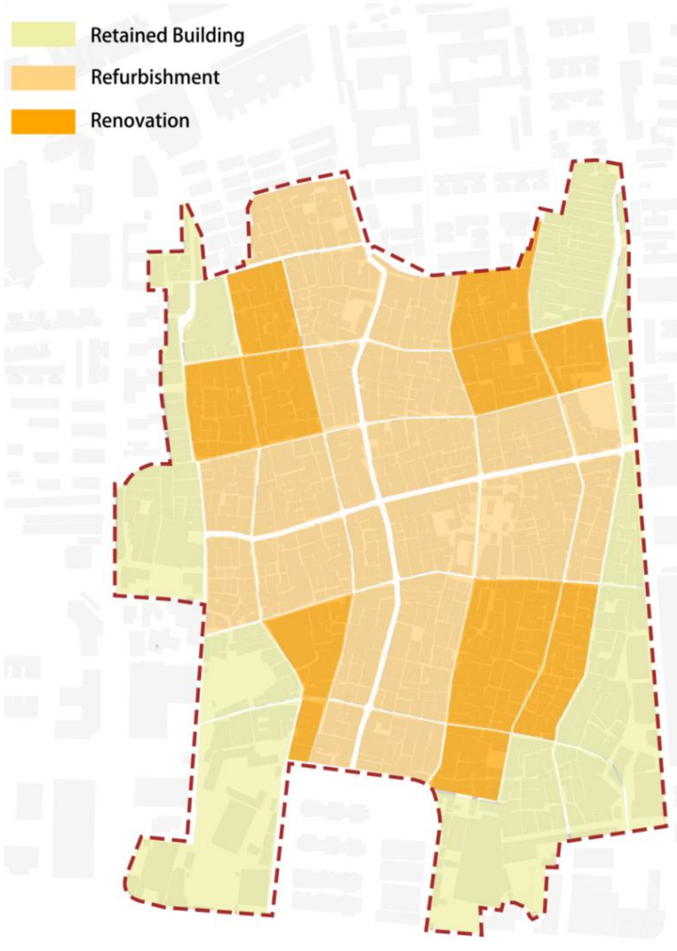
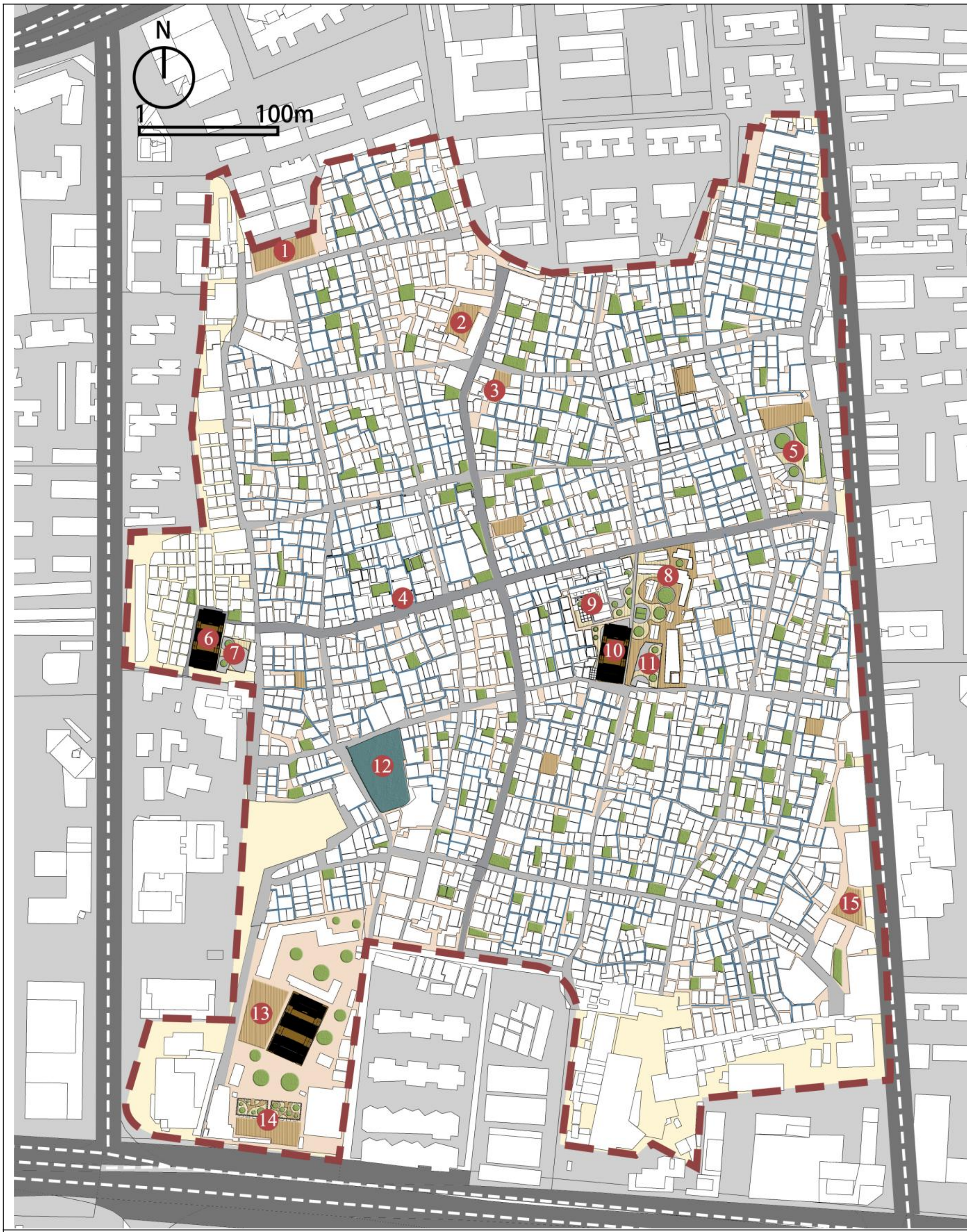


Figure5- 12Renovation Area Division

Source: Author



1.Entrance Space	6.Conserved Ancestral Hall	11.Community Service Center
2.Commercial Space	7.Recreational Rooftop	12. Lakeside Scenic Area
3.Street-side Pocket Space	8.Recreational Space	13.Youth Leisure Space
4.Mixed-Use Space	9.Senior Activity Center	14.Community Resettlement Housing
5.Commercial Leisure Space	10.Ancestral Hall Exhibition Gallery	15.Exit Leisure Space

Figure5-13Shipai Village Renovation Design 1: 1:4500 Master Plan

Source: Author

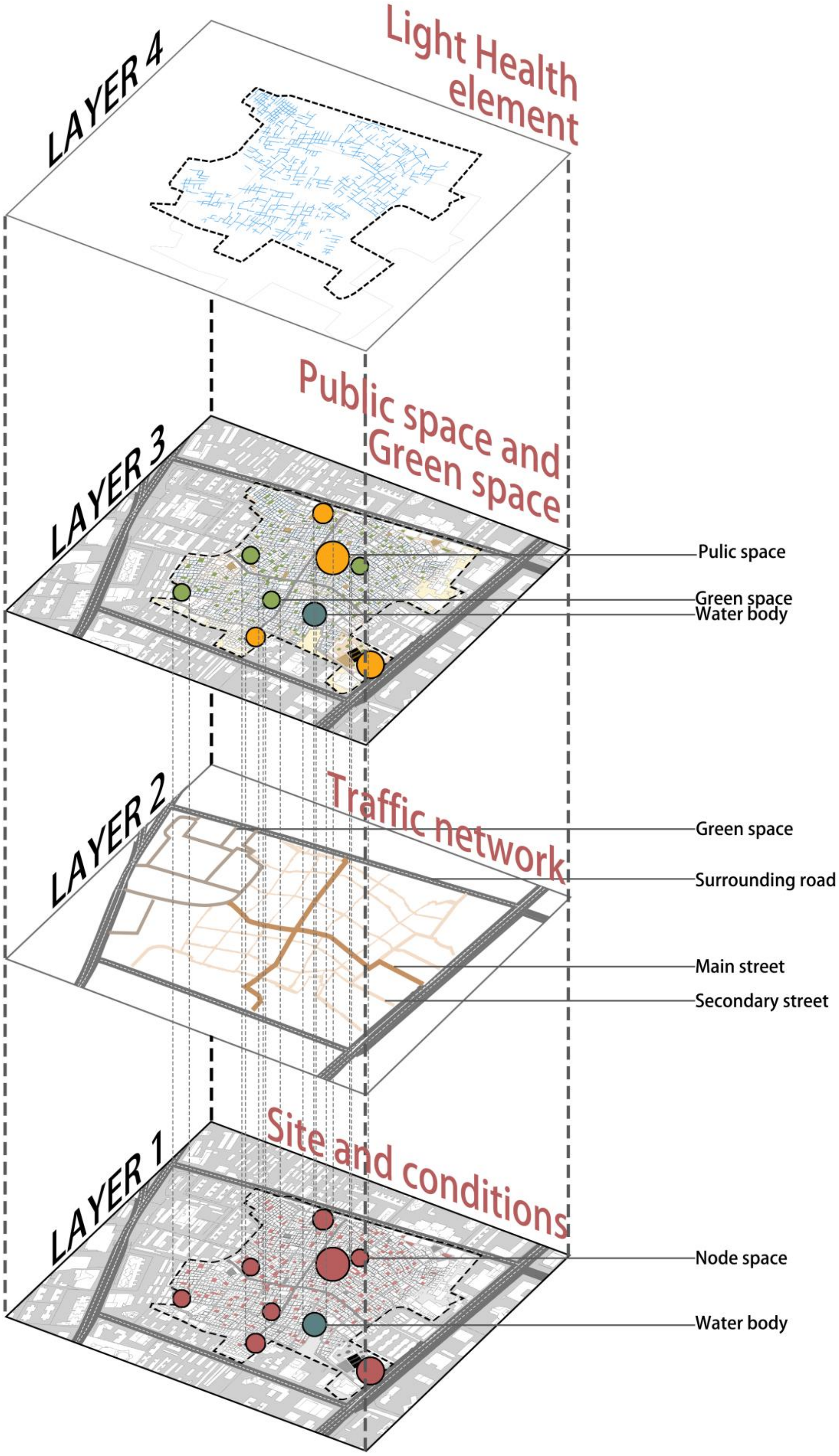


Figure5- 14Shipai Village Renovation Design Exploded Diagram

Source: Author

Figure5- 15Shipai VillageRenovation Design Functional Distribution Map

Source: Author

Figure5- 16Shipai Village Renovation Design – Aerial Perspective (Scale: 1:4000)

Source: Author

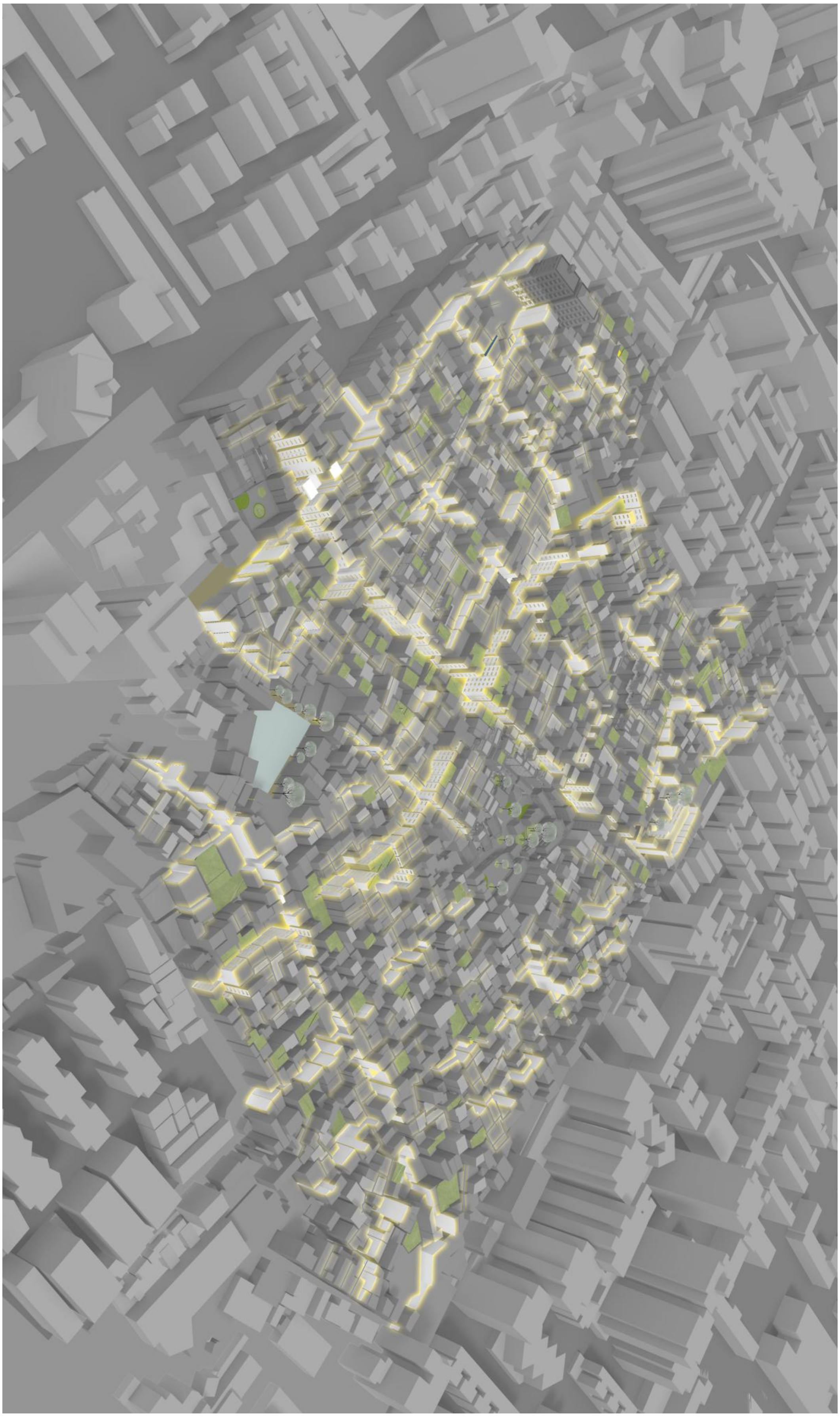


Figure5- 17Street Light Guidance Effect Diagram

Source: Author

5.2.2. Street Renovation

After completing the overall design, the author designed a light-health commercial street to revitalize the community along the primary and secondary streets, as shown in Figure5- 18. Based on the renovation strategy in Figure5- 19, and relying on the street fabric and building function distribution, the original commercial buildings along the main commercial axes were refurbished. In the overall renovation, illegal constructions along the primary and secondary streets were removed, and street-level activity points were added in open areas to promote neighborhood interaction. Along the green axes of the main streets, existing ancestral halls were preserved and integrated with surrounding green spaces, forming a green, restful, and comfortable vibrant street. Additionally, light-guiding components and high-reflectance materials were installed in narrow streets to enhance ground-level illuminance. The partial view rendering shown in Figure5- 20.

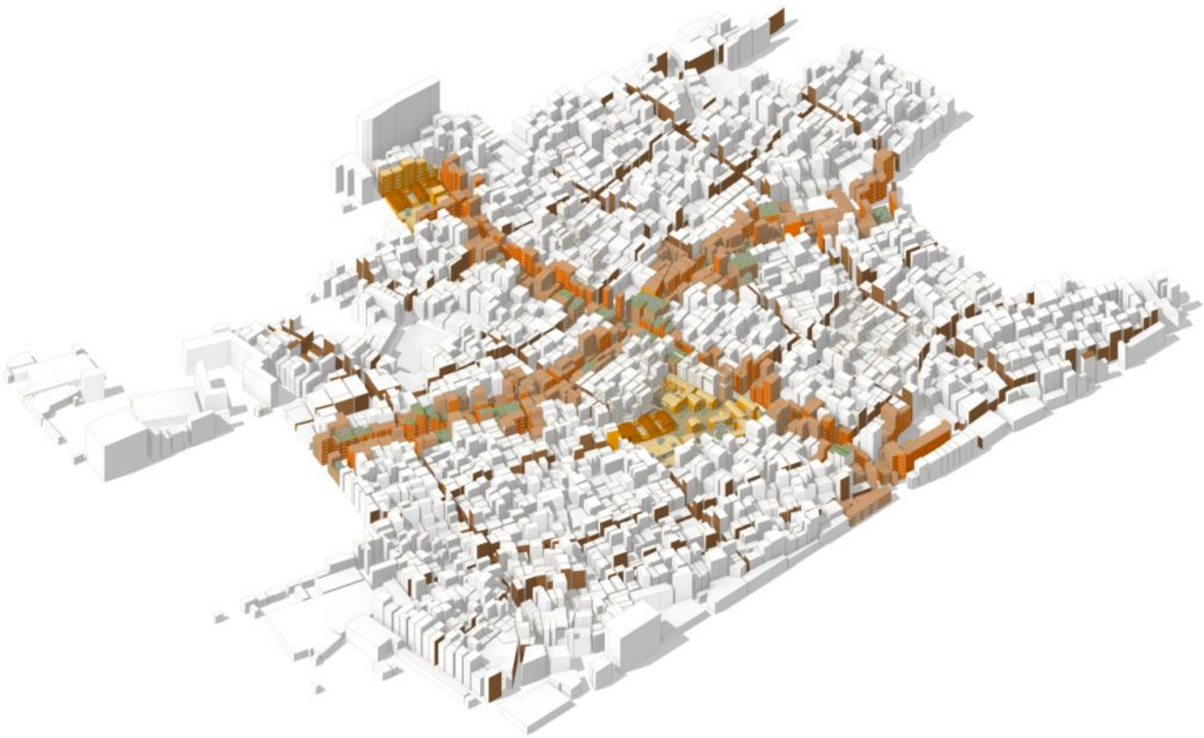


Figure5- 18Street Design Axonometric Diagram

Source: Author

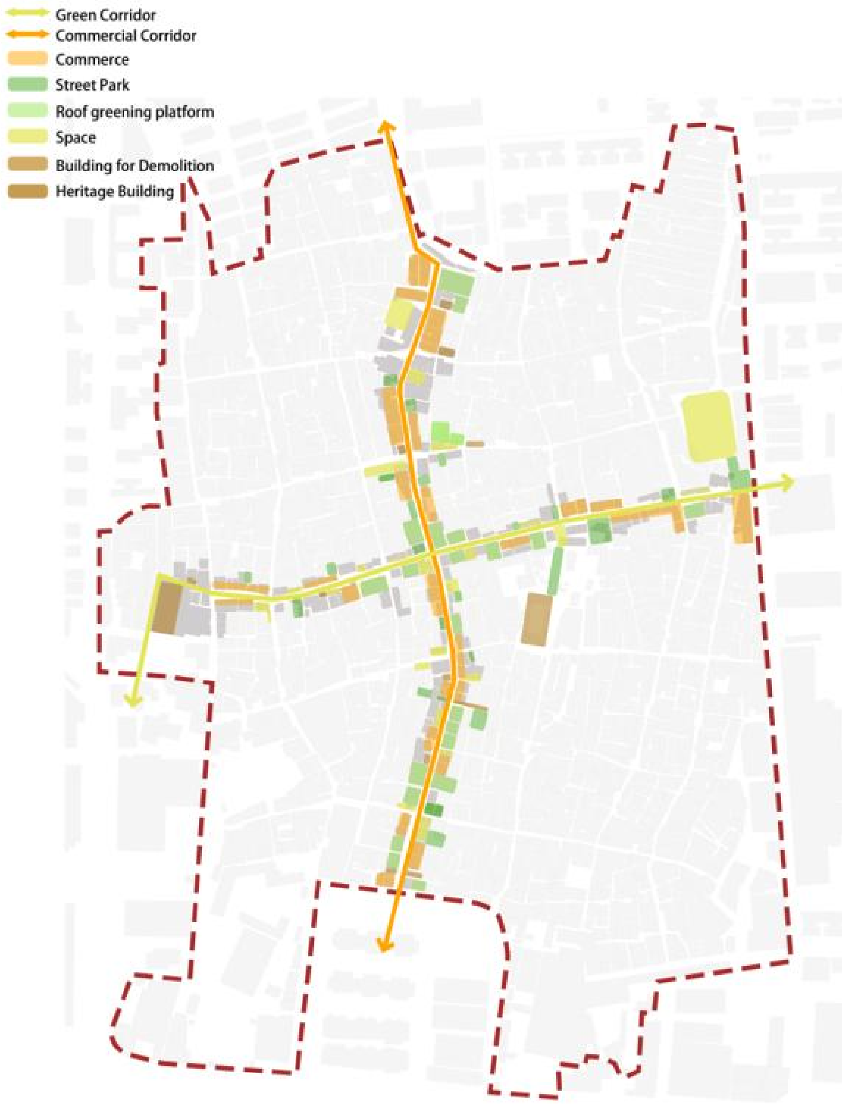


Figure5- 19Main Street Design Strategies

Source: Author

Figure5- 20 Main Street Partial View Rendering

Source: Author

5.2.3. Node Renovation

Based on the existing site conditions and guided by the "micro-regeneration" concept, the author selected three representative nodes for intervention: the Light Health Cultural Plaza Node, the Light Health Residential Node, and the Light Health Mixed-Use Node. These nodes encompass varying functions and degrees of modification, serving as demonstrative prototypes to inform the comprehensive regeneration strategy. The distribution of the nodes is shown in Figure5- 21.

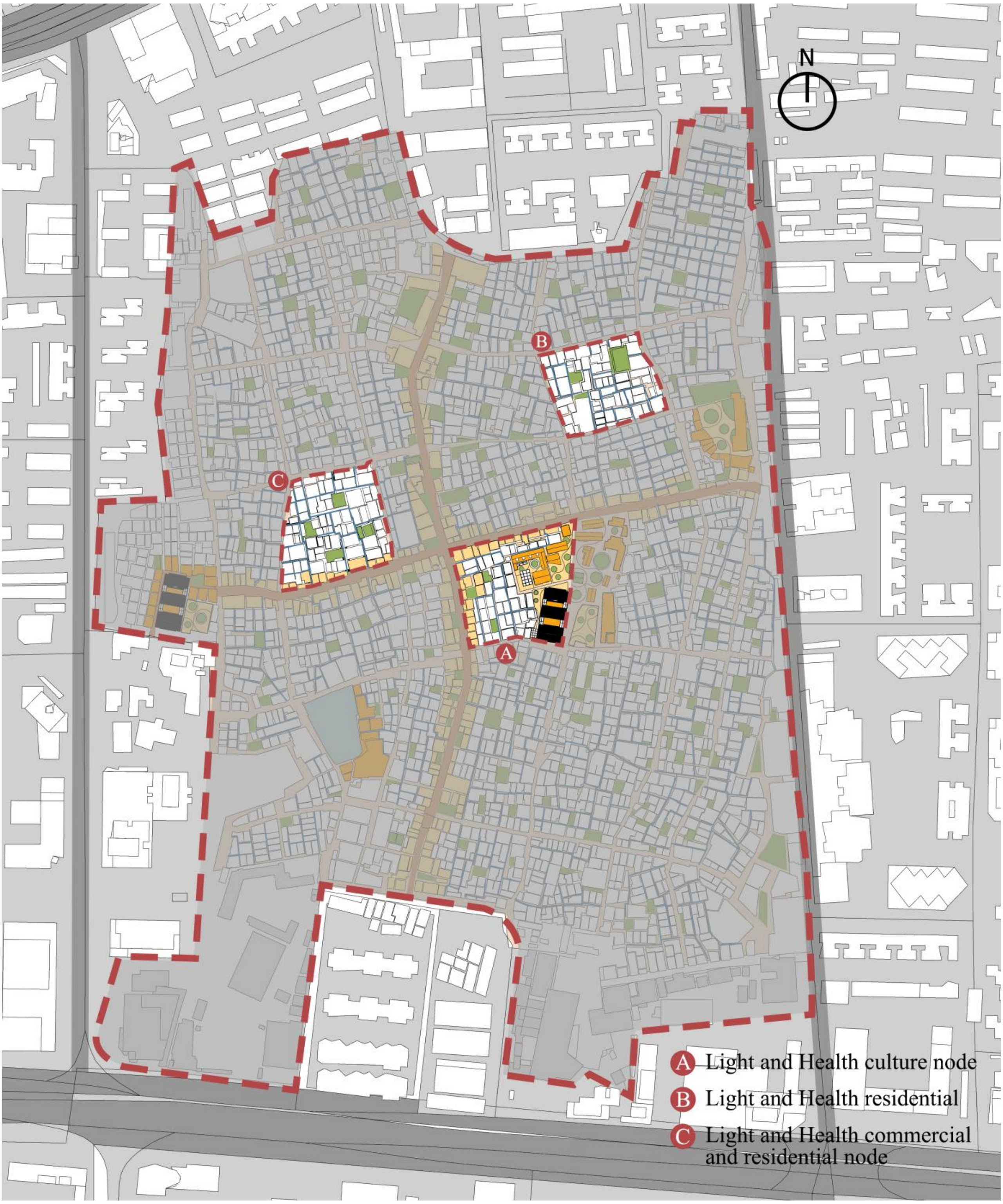
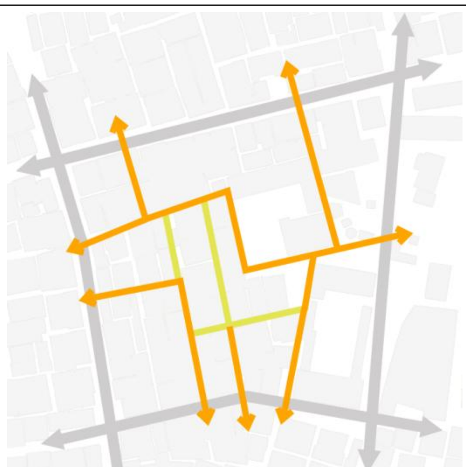


Figure5- 21Renovation Node Plan Distribution

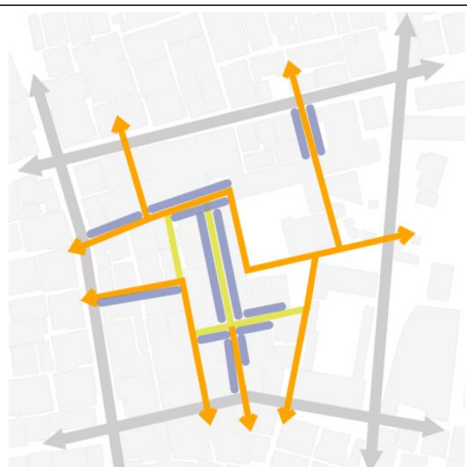
Source: Author

A – Light Health Cultural Square Node

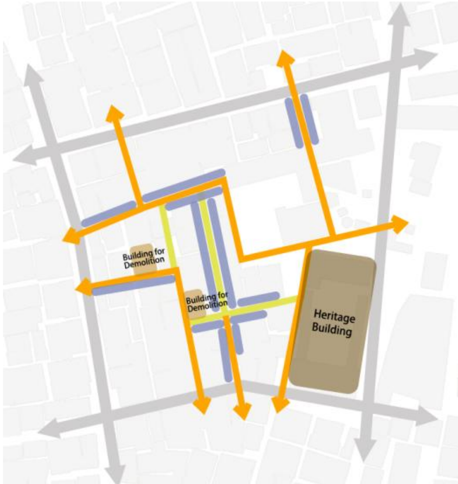
In the design of the Light Health Cultural Square node, we centered on the creation of a light-health-oriented public space, directly addressing existing issues such as fragmented public squares and underutilized rooftop areas. As shown in Figure5- 22, The design began by reorganizing the street network according to the original building fabric. Light-guiding components were installed in poorly lit streets, and high-reflectivity materials were applied to both side walls to enhance illuminance at the street level and optimize light health conditions. Building on this, in areas where passive optimization still resulted in insufficient daylight, selective demolitions were precisely carried out to create multiple well-insolated "sunlight nodes," aiming to extend the duration of residents' outdoor activities. Point-specific functional interventions were then implemented: for instance, pocket parks with excellent daylight conditions were introduced around the open spaces near conserved ancestral halls; interfaces between the streets and internally connected site areas were opened up; and portions of building rooftops were transformed into shared gardens, turning previously underutilized roofs into sunlit communal spaces. Furthermore, the addition of aerial walkways linking various buildings and rooftop gardens significantly enhanced accessibility and continuity within the nodal area, fostering neighborly interaction and community engagement. Ultimately, these measures collectively form a multifunctional, light-health-oriented, and vibrant cultural node., as shown in Figure5- 23 and Figure5- 24.



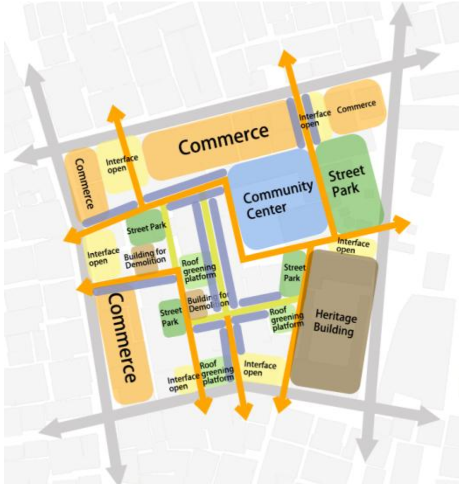
Step 1: Road Network Connectivity



Step 2: Light-Health Optimization



Step 3: Identify Buildings for Demolition and Preservation



Step 4: Point-by-Point Functional Renovation

Figure5- 22Light Health Cultural Square Node Design Strategies

Source: Author

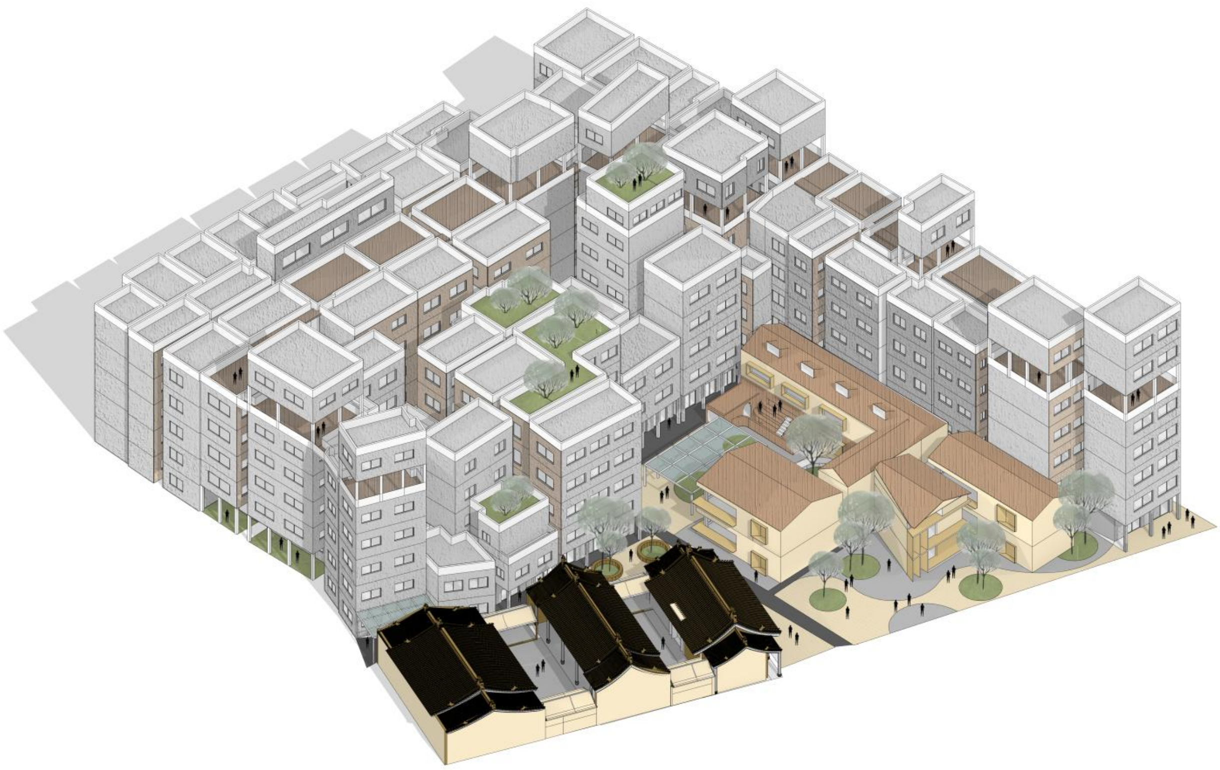


Figure5- 23Axonometric View of the Light Health Cultural Square Node

Source: Author

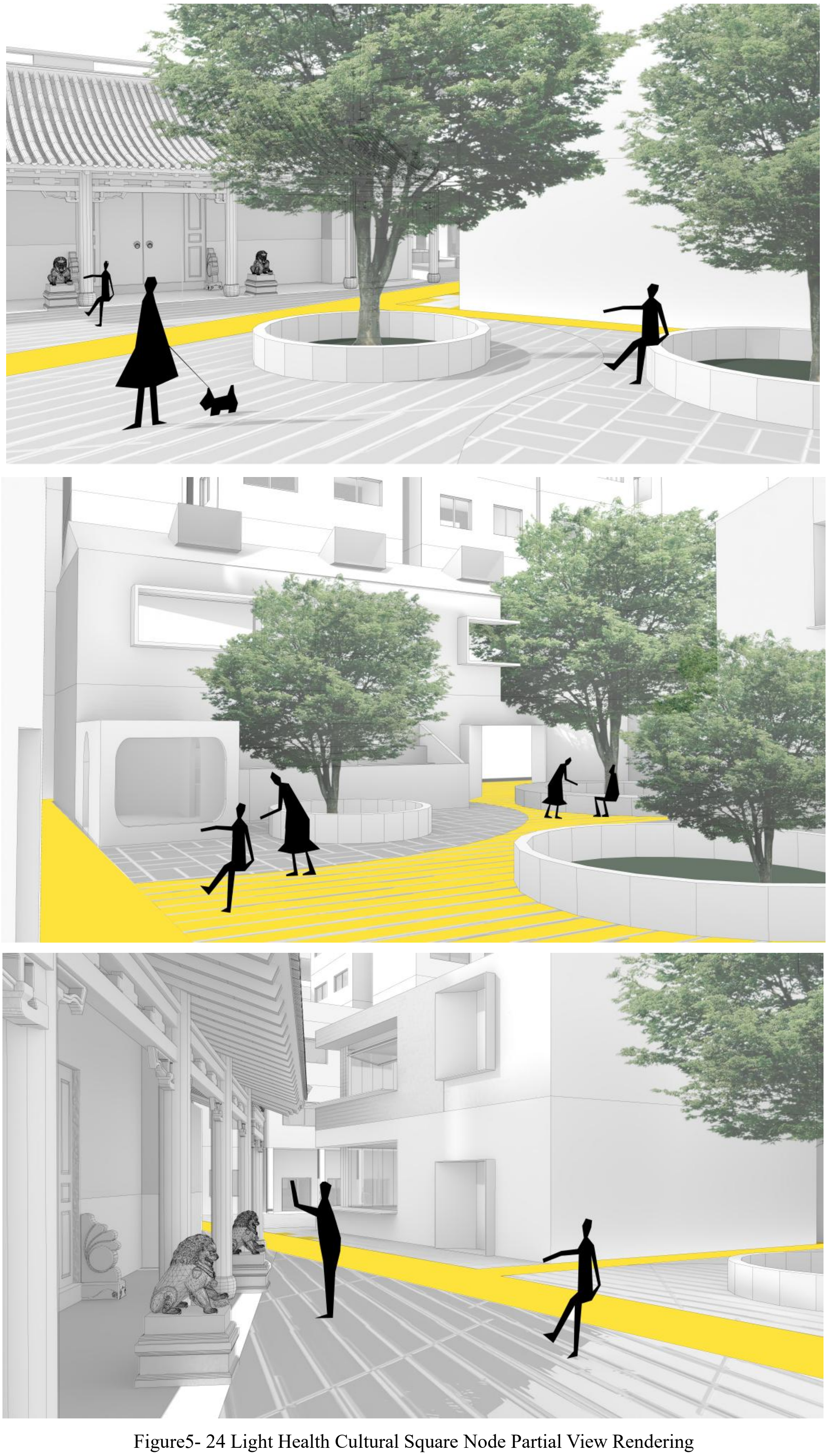


Figure5- 24 Light Health Cultural Square Node Partial View Rendering

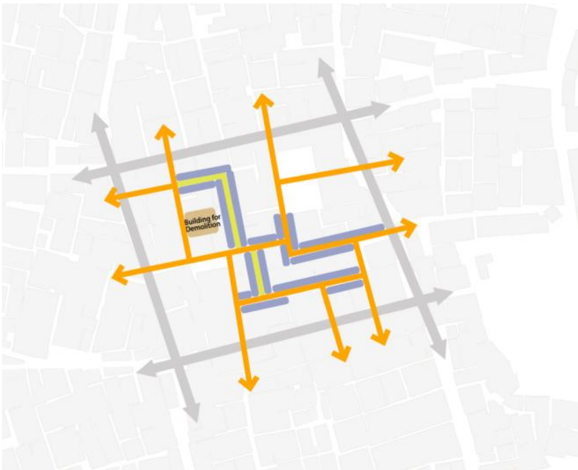
Source: Author

B – Light Health Residential Node

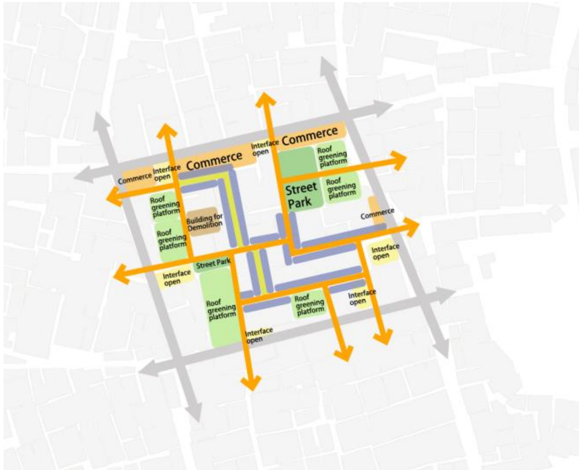
In the design of the Light Health Residential Node, we focused on improving the Light Health levels of residential spaces and enhancing community vitality, following a four-step strategy as shown in Figure5- 25. The design began by reconnecting the street network in accordance with the reconfigured functional layout and its connectivity to main roads, while optimizing streets with poor light health performance through the installation of light-guiding devices and high-reflectivity wall materials to enhance illumination at the street level. Furthermore, aerial walkways were introduced to link different buildings and rooftop activity spaces, significantly improving accessibility and fostering social interaction among residents. Building on this systematic optical and circulational optimization, areas still suffering from severe daylight deficiency were addressed by identifying a minimal number of buildings for selective removal, thereby extending residents' outdoor activity duration. Subsequently, point-specific functional interventions were implemented: scattered and underutilized squares along with well-insolated rooftop spaces were repurposed into multiple small sunlit plazas and pocket parks, while rooftops were transformed into shared gardens—providing centralized drying areas, resting zones, and social spaces that meet daily needs and enrich public life. Ultimately, these integrated measures give form to a vibrant, well-connected, and programmatically diverse Light Health Residential Node, as illustrated in Figure5- 26 and Figure5- 27.

Step 1: Road Network Connectivity

Step 2: Light-Health Optimization



Step 3: Identify Buildings for Demolition and Preservation



Step 4: Point-by-Point Functional Renovation

Figure5- 25Design Strategies of the Light Health Residential Node

Source: Author

Figure5- 26Axonometric View of the Light Health Residential Node

Source: Author

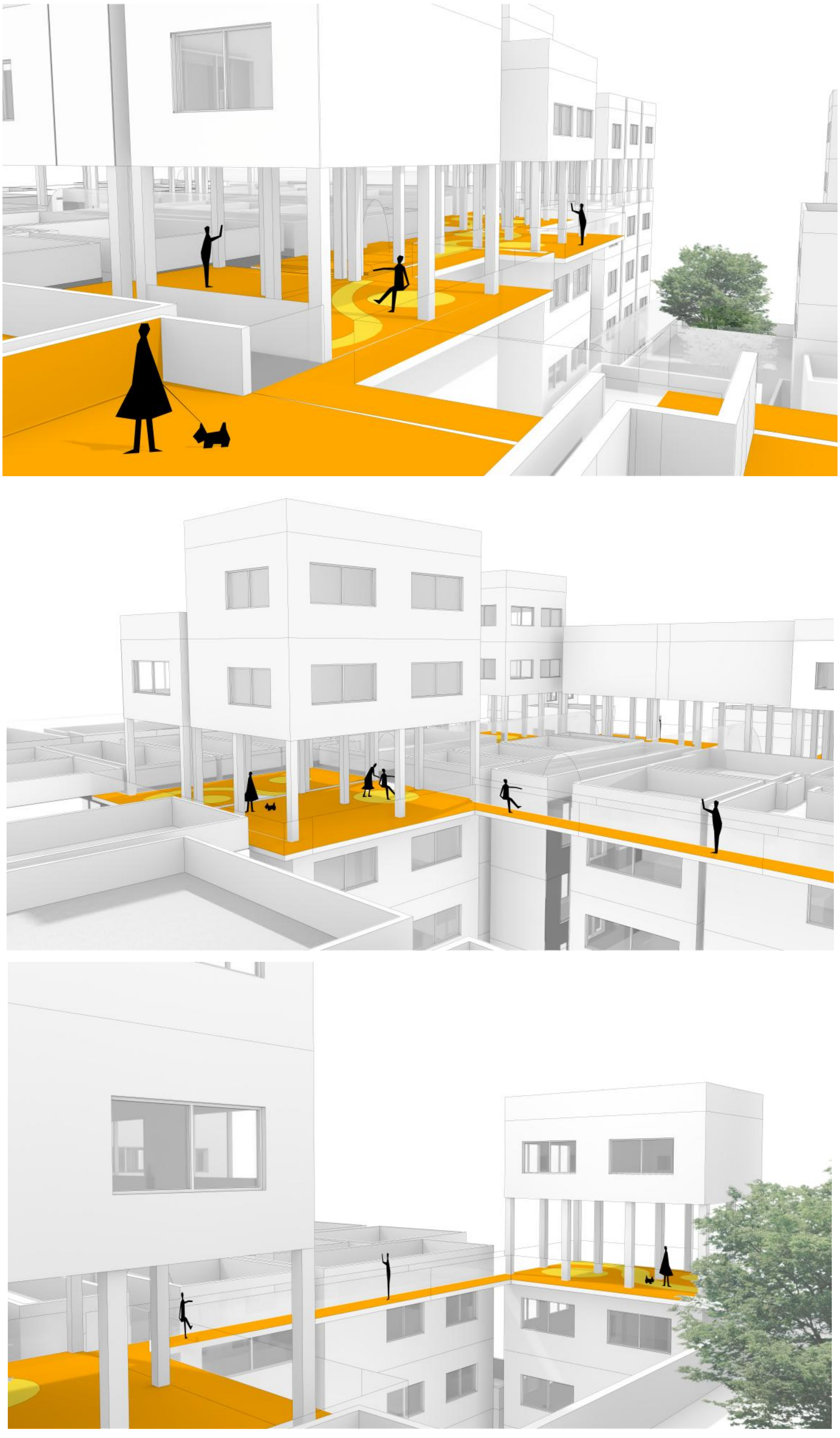


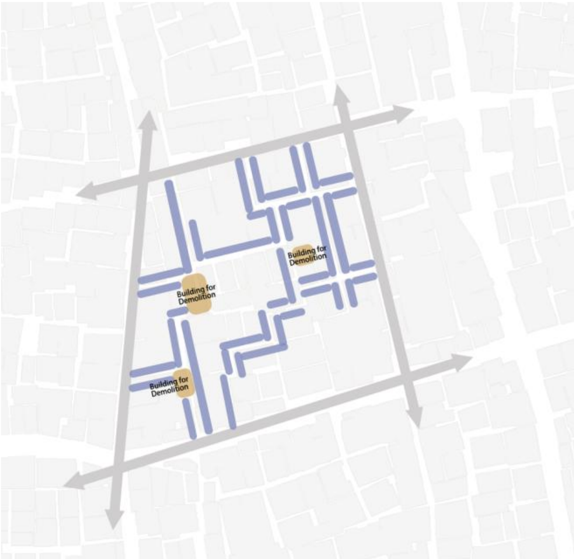
Figure5- 27 Light Health Residential Node Partial View Rendering

Source: Author

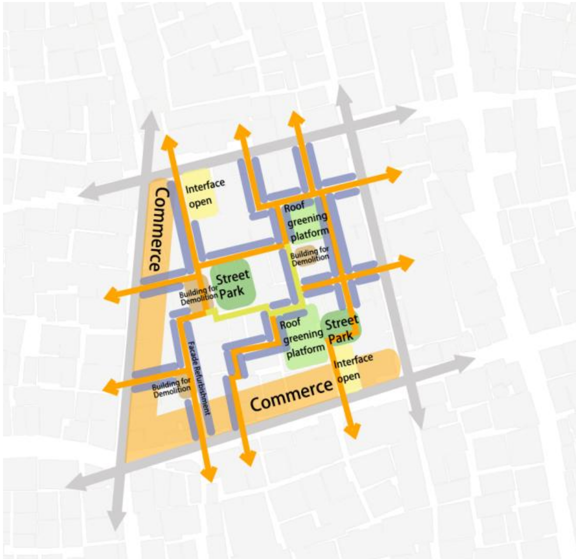
C – Light Health Mixed-Use Node

In the design of the Light Health Mixed-Use Node in this proposal, the focus was on its location adjacent to the main commercial street, aiming to enhance both spatial Light Health and mixed-use needs through subsequent interventions. As shown in Figure5- 28, similar to the Light Health Cultural Node and Light Health Residential Node, the design begins by reorganizing the ground-level street network to enhance connectivity between key functional buildings, while integrating light-guiding components to optimize areas with poor daylight performance. Aerial walkways are introduced to link rooftop plazas and activity spaces, further strengthening spatial integration and daylight sharing.Building upon these systemic improvements, selective demolition of a minimal number of buildings is carried out in areas still experiencing severe daylight deficiency, with the aim of extending residents' outdoor activity duration. Subsequently, point-specific functional interventions are implemented, including the revitalization of street-front commercial buildings and the transformation of scattered internal plazas and underutilized rooftops into multiple well-insolated small squares and pocket parks.Together, these strategies culminate in the formation of a Light Health Mixed-Use Node that integrates commercial and residential functions, as shown inFigure5- 29 and Figure5- 30.

Step 1: Road Network Connectivity | Step 2: Light-Health Optimization



Step 3: Identify Buildings for Demolition and Preservation



Step 4: Point-by-Point Functional Renovation

Figure5- 28Design Strategies of the Light Health Mixed-Use Node

Source: Author

Figure5- 29Axonometric Diagram of the Light Health Mixed-Use Node

Source: Author

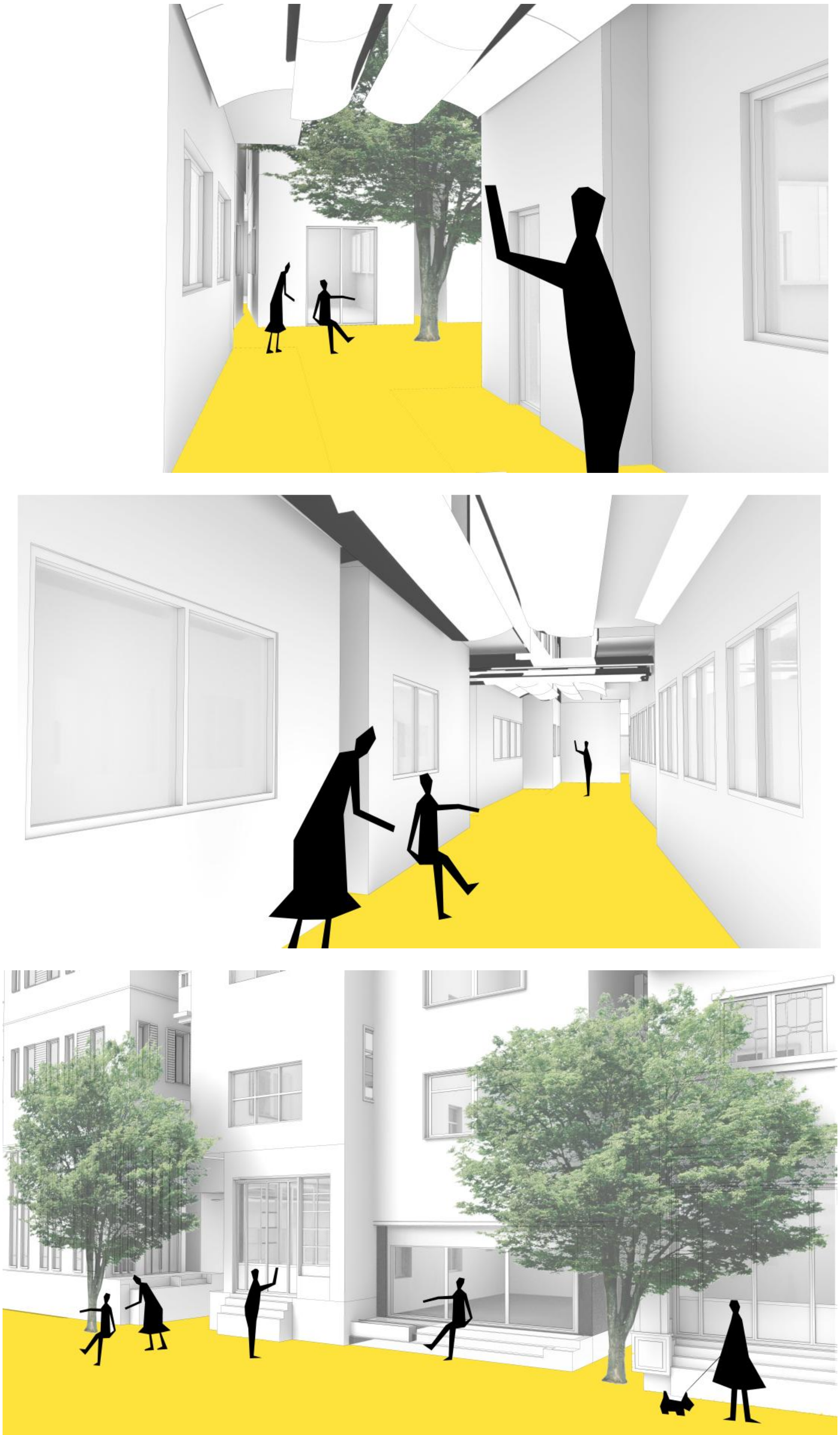


Figure5- 30Light Health Mixed-Use Node Partial View Rendering

Source: Author

5.2.4. Individual Building Renovation

A representative building within the Light Health Cultural Node was selected for renovation, where poorly lit interiors persist even after the installation of light-guiding devices in the adjacent streets and alleys(Figure5- 31). By implementing two strategies—introducing a “light well” and applying high-reflectance materials to window surfaces—the renovation improves the low illuminance and poor uniformity in the deep interior spaces. Floor plans before and after the renovation and schematic diagram of light well optimization are shown in the figure(Figure5- 32, Figure5- 33, Figure5- 34).

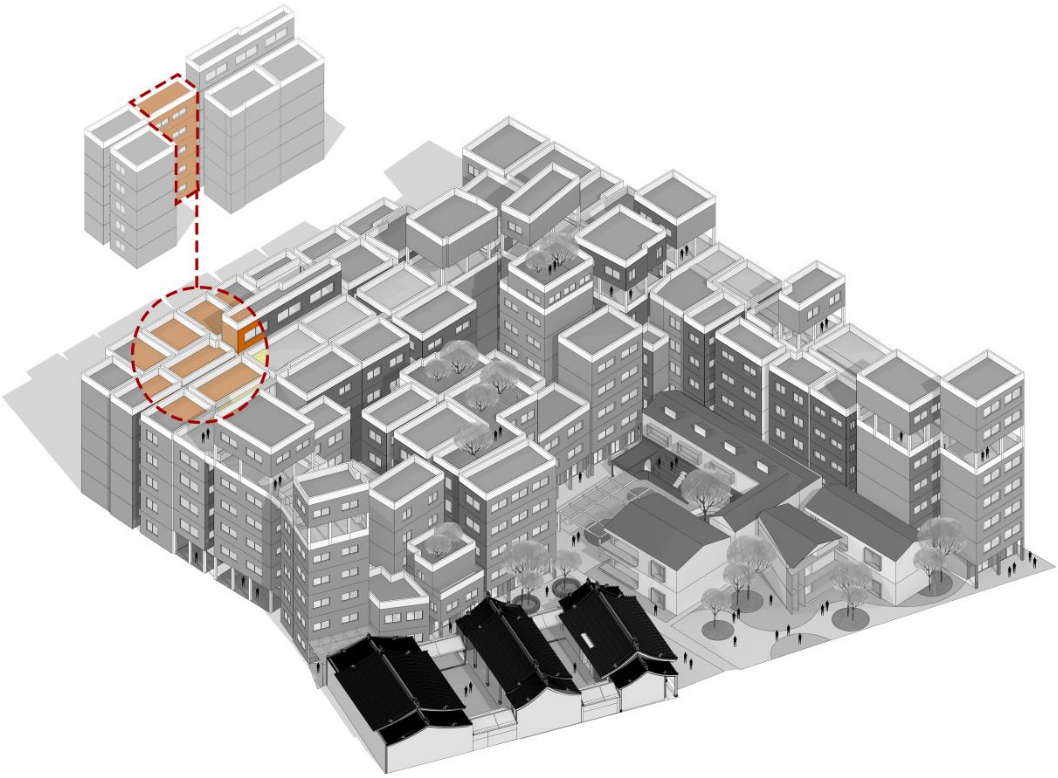


Figure5- 31Location Diagram of the Renovated Building Unit

Source: Drawn by the autho

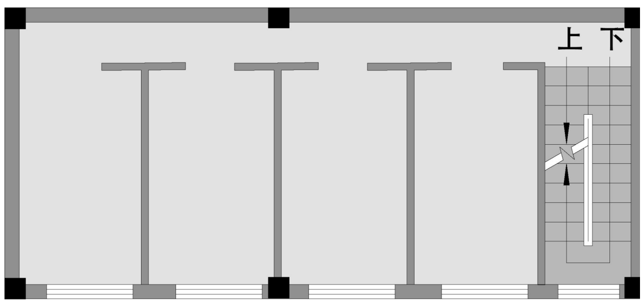


Figure5- 32Existing Floor Plan of the Building Unit 1:50

Source: Author

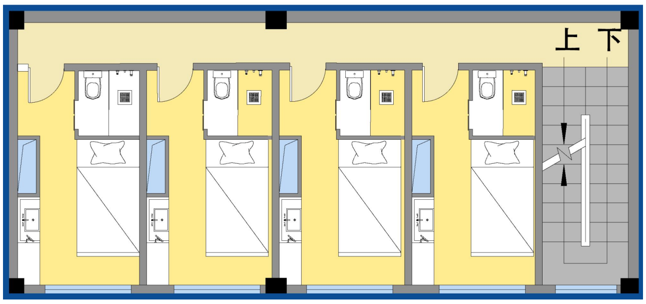


Figure5- 33Renovated Floor Plan of the Building Unit 1:50

Source: Author

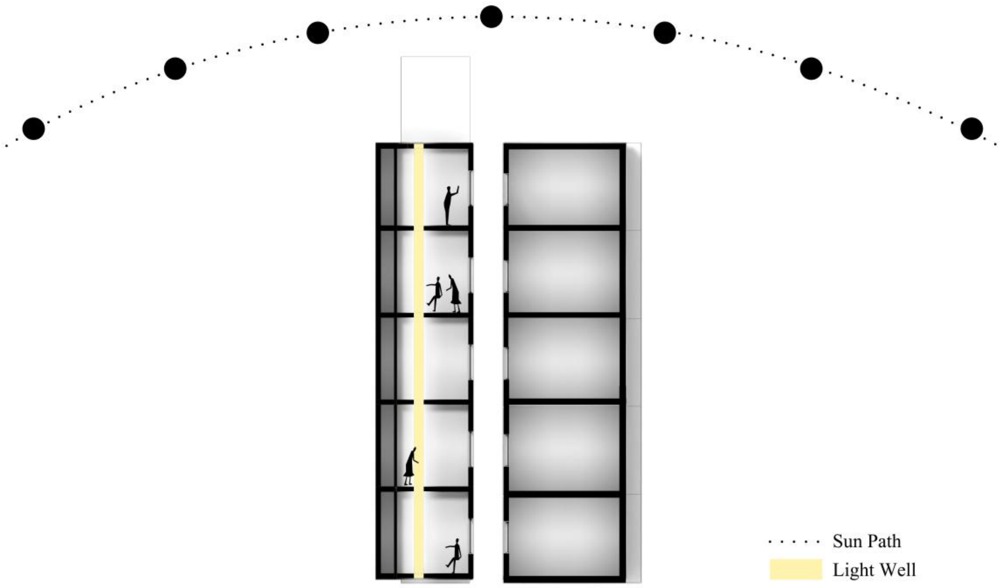


Figure5- 34 Schematic Diagram of Light Well Optimization

Source: Author

5.2.5. Demolition Compensation

The renovation of Shipai Village faces multiple practical obstacles, and its update process has been difficult to advance effectively. Besides property rights issues, villagers generally show low willingness to participate in renovations. Currently, the village can generate nearly 400 million RMB annually from house rentals, with rental income far exceeding collective dividends; therefore, most villagers are unwilling to give up their existing income [58].Therefore, in line with the core principles of urban renewal—which prioritize preservation and improvement, strictly limit large-scale demolition and construction, and advocate for context-sensitive and diversified approaches—this study drawing on the renovation approach of another key redeveloped urban village in Guangzhou, Liede Village, which adopted a “government supervision, village collective-led, market-driven” model[60], a new model was pioneered in property rights handling: villagers exchanged land ownership (via land auctions) for developer-provided housing (resettlement units), accompanied by a reasonable “one-for-one” compensation plan. The concept of “compensation and resettlement” indicates that the transfer of residents’ property rights requires financial or material compensation along with relocation.

Accordingly, drawing inspiration from the market-oriented regeneration model exemplified by Liede Village—centered on "property-right exchange"—this study calculates the demolition area and spatial distribution for Shipai Village, as detailed in Table5- 3 and Figure5- 35. To compensate for the loss of original living space resulting from demolition, resettlement housing of equivalent floor area is proposed within the peripheral vacant land inside the site boundary, illustrated in Figure5- 36 and Figure5- 37. with reference to current compensation measures ,this "one-for-three" compensation strategy aims to establish a realistic and context-sensitive regeneration pathway tailored to the actual conditions of Shipai Village.

Table5- 3Demolition Area and Corresponding Compensation

Source: Author

Demolition Area (㎡)	Compensation Area (㎡)	Compensation for Building Ground Floor Area (㎡)	Compensation for Number of Floors (Floors)	Compensation for Number of Buildings (Buildings)
7302	22262.4	927.6	36	6

Figure5- 35Area Distribution

Source: Author

Figure5- 36Two Relocation Housing Location Diagram

Source: Author

Figure5- 37Two Relocation Housing Axonometric View

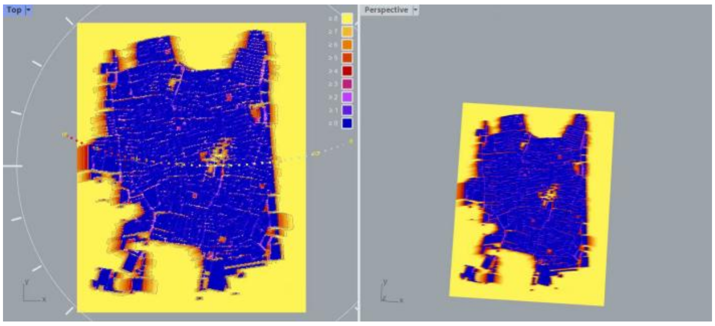
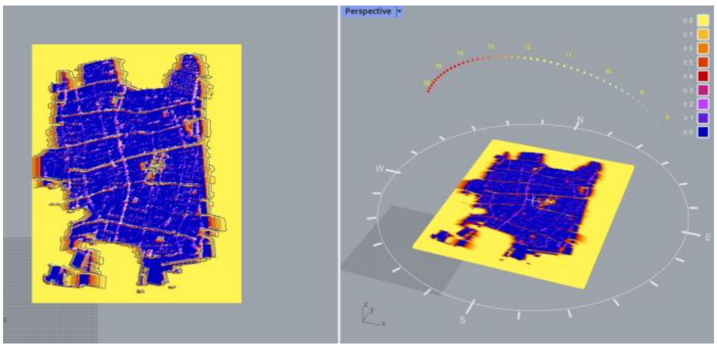
Source: Author

5.2.6. Comparative Evaluation Before and After Renovation

(1) Overall Comparison Before and After Renovation (Table5- 4):

Table5- 4Comparison of Overall Renovation Before and After on the Summer Solstice

Source: Author

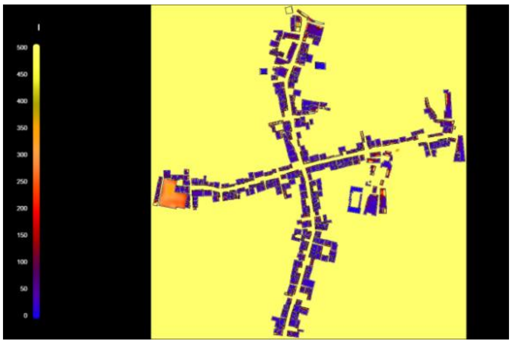
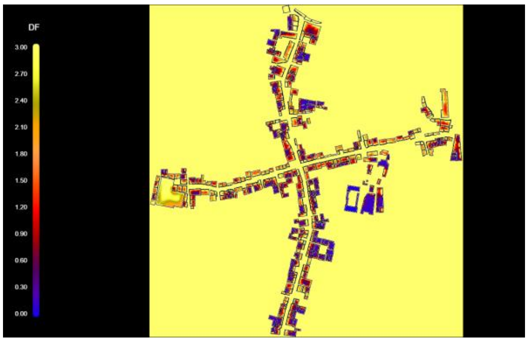
	Natural Light Exposure Duration
Before Renovation	
After Renovation	

(2) Comparison Before and After Street Renovation

Comparison of Main Streets Before and After Renovation (Table5- 5):

Table5- 5Comparison of Main Streets on April 21 at 12:00 Before and After Renovation

Source: Author

	Bottom-level illuminance, illuminance uniformity	Daylight factor
Before Renovation		
After Renovation		

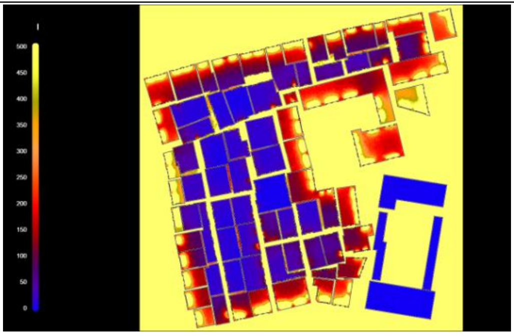
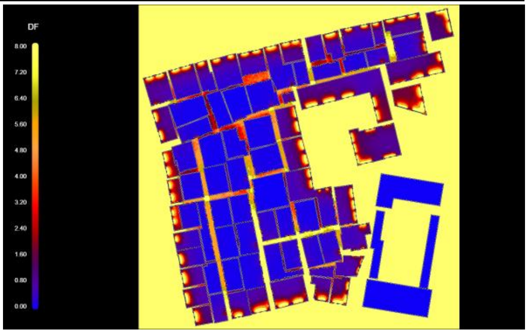
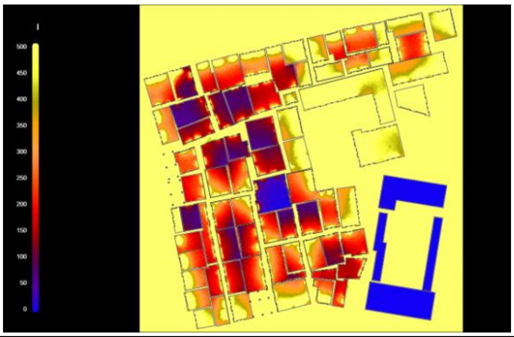
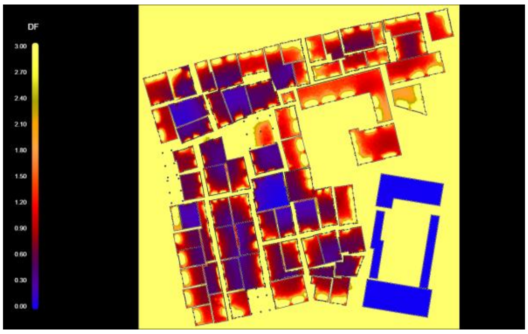
(3)Node Renovation Comparison Before and After

Light Health Cultural Node Renovation Comparison Before and After (Table5- 6):

Table5- 6Light Health Cultural Node Renovation Comparison on April 21st, 12:00

Source: Author

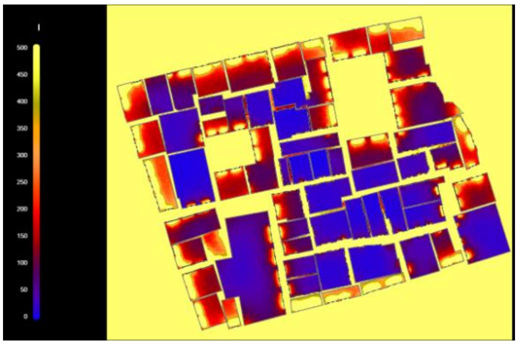
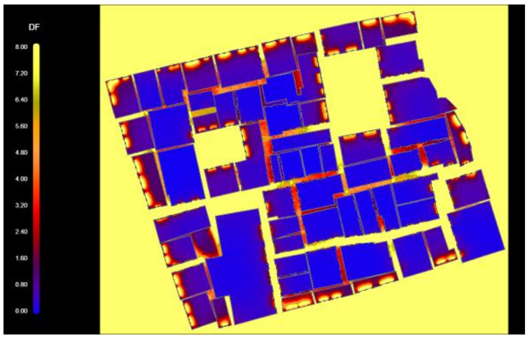
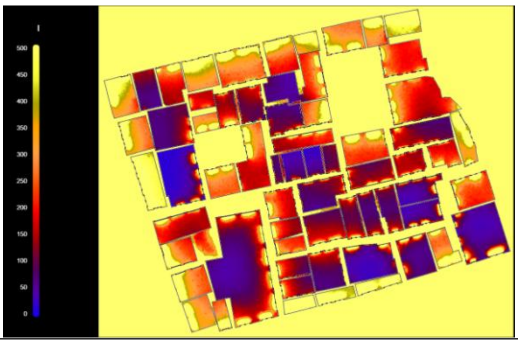
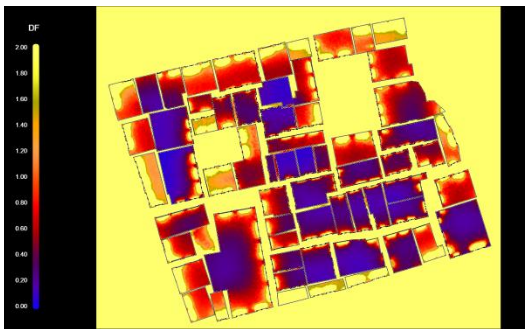
	Bottom-level illuminance, illuminance uniformity	Daylight factor

Before Renovation		
After Renovation		

Light Health Residential Node Renovation Comparison Before and After (Table5- 7):

Table5- 7Light Health Residential Node Renovation Comparison on April 21st, 12:00

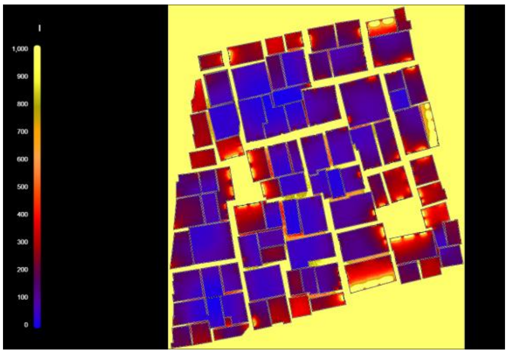
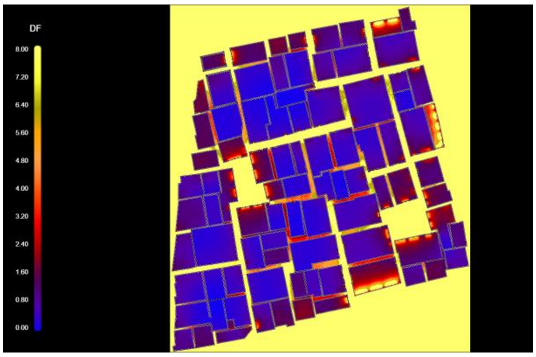
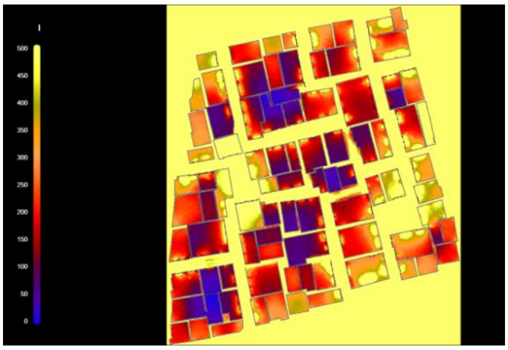
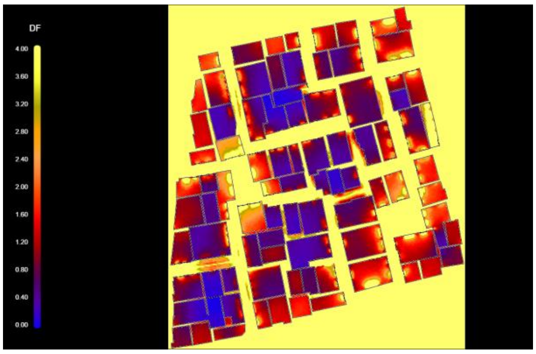
Source: Author

	Bottom-level illuminance, illuminance uniformity	Daylight factor
Before Renovation		
After Renovation		

Light Health Mixed-Use Node Renovation Comparison Before and After (Table5- 8):

Table5- 8Light Health Mixed-Use Node Renovation Comparison on April 21st, 12:00

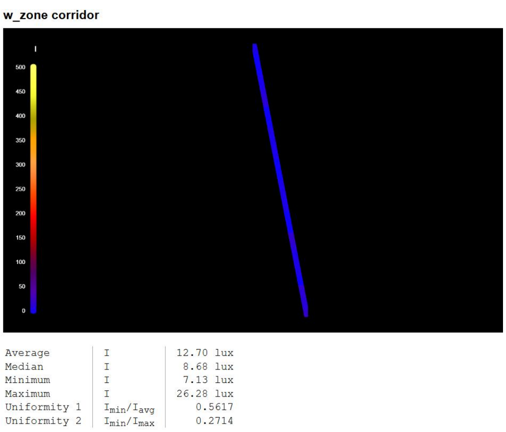
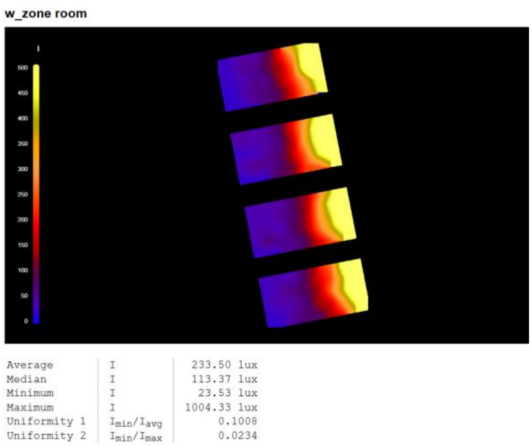
Source: Author

	Bottom-level illuminance, illuminance uniformity	Daylight factor
Before Renovation		
After Renovation		

(4)Individual Building Renovation Comparison Before and After (Table5- 9 andTable5- 10):

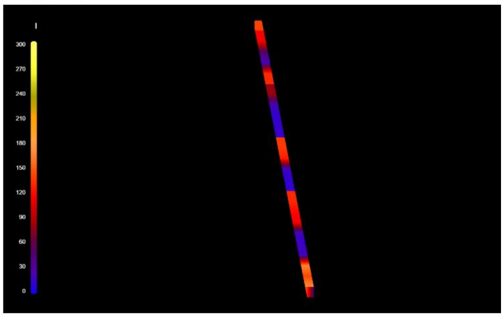
Table5- 9Individual Building Renovation Comparison on April 21st, 12:00

Source: Author

	Corridor horizontal illuminance and uniformity	Room horizontal illuminance and uniformity
Before Renovation		

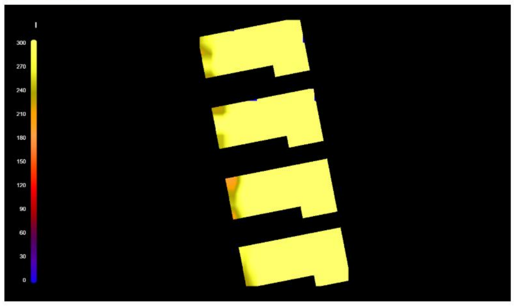
After Renovation

w_zone corridor



Average	I	13.76 lux
Median	I	10.00 lux
Minimum	I	8.00 lux
Maximum	I	27.55 lux
Uniformity 1	I_{min}/I_{avg}	0.5814
Uniformity 2	I_{min}/I_{max}	0.2903

w_zone room

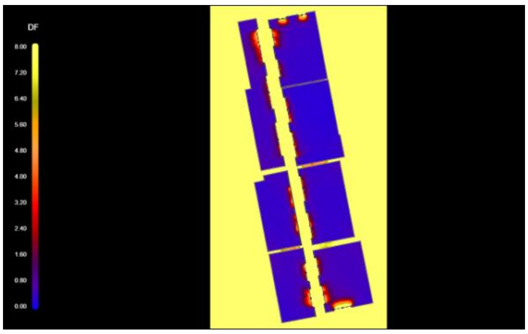
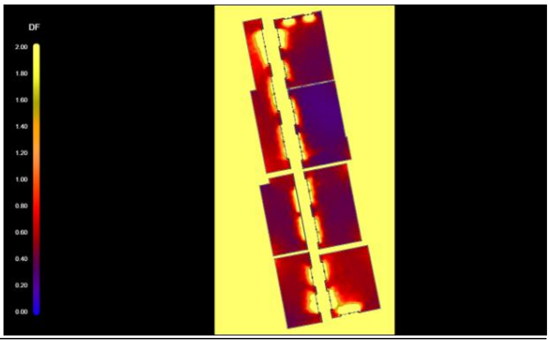


Average	I	247.55 lux
Median	I	125.38 lux
Minimum	I	23.46 lux
Maximum	I	1056.02 lux
Uniformity 1	I_{min}/I_{avg}	0.0948
Uniformity 2	I_{min}/I_{max}	0.0222

Comparison of Daylight Factor in Individual Building:

Table5- 10Comparison of Daylight Factor in Individual Building on April 21 at 12:00 Before and After Renovation

Source: Author

	Before Renovation	After Renovation
Daylight factor		

5.3. Chapter Summary

This chapter takes Shipai Village in Guangzhou as a case study, applying Light Health prototype renovation strategies to the specific site and implementing an evidence-based evaluation of its Light Health-oriented urban village renewal design. A core principle of "micro-regeneration first, demolition as supplement" was established throughout the process.The study begins with a comprehensive situational analysis of Shipai Village, examining aspects such as transportation, building height, functional layout, public space distribution, building quality, and daylight hours. This analysis reveals critical issues within its high-density environment: severe natural daylight deficiency, poor spatial light environmental quality, and insufficient public activity areas. Based on these findings, zones with varying regeneration potential were delineated.Building on this assessment, targeted

Light Health renovation strategies were developed and applied across four interconnected scales: overall, street, node, and individual building. Passive retrofit measures were prioritized—including reorganization of the street network, installation of light-guiding components in alleyways, and application of high-reflectivity materials. Only when these measures proved insufficient were minimal selective demolitions carried out, transforming the cleared sites into community "sunlight nodes."The effectiveness of the strategies was verified through pre- and post-intervention comparisons of light environment indicators, measuring improvements in natural light exposure duration, illuminance levels, and spatial uniformity.Beyond design strategies, the chapter also explores implementation pathways for urban village regeneration. By considering Shipai Village's complex property rights structure, resident preferences, and drawing lessons from the Liede Village redevelopment model, it proposes context-sensitive implementation pathways and cooperative frameworks. This provides a systematic, actionable solution—from design to on-ground realization—for Light Health-oriented renewal of high-density urban villages.

Conclusion

This study adopts Shipai Village in Guangzhou as a representative case, grounded in the research perspective of "Light Health–oriented urban village regeneration." Building on existing theories and applications of Light Health domestically and internationally, as well as current light environment evaluation indicators and their implications, the study proposes a set of Light Health impact indicators. Through field investigations, data measurements, and resident interviews, the current light environment conditions of Shipai Village—a typical high-density urban village—were assessed, leading to the identification of resident needs. Guided by the "micro-regeneration" concept, the study proposes Light Health–oriented renewal strategies tailored to different typical spatial types, aiming to encourage residents to adopt a Light Health–conscious lifestyle. The main conclusions derived from the research are as follows:

(1)Translation of Light Environment Indicators into Light Health Metrics: By systematically reviewing the mechanisms through which the light environment affects human health, this study demonstrates that light not only impacts visual comfort but also influences circadian rhythm, psychological state, and social interaction through non-visual pathways. Based on domestic and international standards for healthy buildings, existing light environment evaluation indicators were summarized. Traditional light environment indicators were then mapped to Light Health needs, with core indicators selected, including Natural Light Exposure Duration, horizontal illuminance, illuminance uniformity, and morning high illuminance, alongside proposed standard thresholds more aligned with health requirements. Additionally, domestic and international case studies on light environment renovation were collected and analyzed, including practical renovation methods and cases demonstrating that improving natural daylighting effectively enhances residents’ physical and mental well-being. This process provides both a theoretical foundation for urban village Light Health research and practical support for subsequent renovation strategy applications.

(2)Current Situation Survey and Light Health Issues: Focusing on Shipai Village, this study analyzed the current light environment through a combination of field surveys, measurements, and resident interviews. The investigation shows that the village’s building layout is extremely compact, mostly adopting the typical "handshake building" form of urban villages, with measured inter-building spacing primarily between 0.1 and 2.5 m. This high-density spatial form results in widespread Light Health issues across various spaces, including building clusters, primary and secondary streets, and individual buildings. For example, main street widths range from 1.6 to 7.1 m, with height-to-width ratios generally between 0.05 and 0.33; secondary streets are 0.75 to 2.7 m wide, with extremely low height-to-width ratios, most below 0.1, and the lowest as little as 0.03. Measured data show that narrow alleys have daytime average illuminance below 100 lx, whereas wide streets can reach 8,000 – 9,000 lx at noon on sunny days. Residential units typically have widths of 2.45 – 5 m, depths of 3 – 5 m, and small areas of 8 – 22 m^2, with most ground-floor rooms under 100 lx, almost entirely reliant on artificial lighting, while upper floors can reach 2,000 – 7,000 lx. Public spaces, such as ancestral hall squares, have illuminance of approximately 2,000 – 4,500 lx on sunny days but are limited in number and scattered. Interviews indicate that residents of all ages, occupations, and living habits are affected physiologically and psychologically by poor light conditions. Overall, Shipai Village exhibits a high-density, low natural light exposure, low illuminance, low uniformity, and spatially varied light environment, with mismatches between current light conditions and residents' needs, highlighting Light Health issues that require intervention.

(3)Light Health Prototype Renovation Strategies: Based on field survey findings, Light Health renovation measures were proposed for typical indoor and outdoor spatial prototypes. For instance, in narrow streets and alleyways, the installation of light-guiding devices and application of high-reflectivity aluminum foil on walls enhanced ground-level Light Health metrics, improving residents' living convenience and comfort. To address Light Health issues in individual buildings, high-reflectivity aluminum foil applied between window openings can introduce more street-level light into interiors, while the insertion of light wells in deep-plan spaces alleviates poor illumination and ensures high morning light levels to effectively regulate residents' circadian rhythms. In cases where passive retrofitting remains insufficient, scattered demolition within building clusters achieves an optimal balance between demolition area and daylight enhancement. Ultimately, this study establishes a comprehensive set of Light Health renewal strategies for various spatial prototypes, laying a theoretical and methodological foundation for subsequent design practices in Shipai Village.

(4)Application and Outcomes of Light Health Renovation Strategies in Shipai Village: The Light Health prototype strategies were applied to specific scenarios in Shipai Village, including overall, street, node, and individual building levels, verifying the strategies' practical feasibility. Post-renovation, Light Health indicators such as horizontal illuminance, Natural Light Exposure Duration, and morning illuminance improved significantly, effectively addressing previous Light Health issues, including circadian rhythm, visual comfort, and safety concerns. Cluster demolitions created more open spaces, and previously underutilized rooftops and open areas were transformed into Light Health drying areas, public activity areas, and rooftop gardens, guiding residents toward healthier lifestyles and providing venues for previously unavailable Light Health activities. Furthermore, the market-based property swap model of Liede Village can be referenced in practice to overcome challenges such as complex property rights and low resident willingness, providing a full-process solution for implementing Light Health-oriented urban village renovations.

Overall, this study not only accomplishes the theoretical translation of light environment indicators into Light Health metrics, but also proposes differentiated spatial regeneration strategies applicable to high-density urban villages. Their feasibility and effectiveness have been verified through real-site application, providing both conceptual frameworks and practical methodologies for Light Health–oriented urban village regeneration. This offers a valuable reference for future projects of similar nature.

Although this study has explored Light Health-oriented urban village renovation and achieved certain results, several aspects remain to be further developed:

(1)This study simplified the environment for modeling under measured conditions but did not fully incorporate factors such as furniture layout, material properties, and residents' detailed behavioral patterns. Future research should integrate real site details to enhance model realism and explore the combination of property rights, policies, and community participation mechanisms to improve applicability and implementability of Light Health renovations.

(2)This study focuses primarily on Shipai Village under the Guangdong climate and proposes corresponding Light Health renovation strategies. However, urban villages vary widely, and light-climate characteristics and health needs differ across regions and populations. Future research should validate findings across broader regions and diverse populations and develop context-appropriate design strategies.

(3)This study emphasizes optimization at the levels of clusters, streets, nodes, and individual buildings but involves limited research on shading design and dynamic light environment adjustment. Subsequent research can explore finer spatial scales, incorporate additional design variables, and conduct multi-level experimental validation to more comprehensively improve site health via Light Health indicators.

(4)While the proposed Light Health evaluation indicators and threshold values reflect certain health needs, limitations remain under mixed light environments and dynamic spectral conditions. Future work can introduce dynamic circadian indicators such as CS (Circadian Stimulus) and EML (Equivalent Melanopic Lux), integrating interdisciplinary research results to develop a more precise and scientific indicator system, enhancing both research accuracy and applicability.

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Appendix

Shipai Village, Guangzhou – Questionnaire on Light Health and Spatial Environment Experience

Dear Resident/Visitor of Shipai Village,

Hello! I am a graduate student from the School of Architecture at South China University of Technology in Guangzhou, currently conducting academic research on "Light Health-Oriented Spatial Renovation in High-Density Urban Villages." Your honest feedback will provide crucial data for this study. The questionnaire is anonymous, and all data will be used solely for academic analysis. Thank you sincerely for your support and cooperation!

I. Basic Information

1. Your identity:

□ Local villager (with self-built house) □ Local tenant □ Business owner/staff □ Visitor/Other

2. Your age:

□ Under 18 □ 18-25 □ 26-35 □ 36-50 □ 51-65 □ Over 65

3. How often do you live/work in Shipai Village?

□ Daily □ 3-5 times per week □ 1-2 times per week □ 1-3 times per month □ Occasional visits

4. On average, how many hours per day do you spend indoors (at home/shop) under natural light?

□ Less than 1 hour □ 1-3 hours □ 3-5 hours □ More than 5 hours

II. Light Environment Experience and Evaluation

5. How do you perceive the brightness of the following spaces during the daytime? (1-5 points, 1=Very dim, 5=Very bright)

Space Type	1	2	3	4	5
Main indoor space where you live/work	□	□	□	□	□
Main streets (connecting Tianhe Rd. and Huangpu Ave.)	□	□	□	□	□

Narrow alleys (lanes and gaps between buildings)	□	□	□	□	□
Public squares/activity nodes (e.g., Pan Clan Ancestral Hall, Shipai Village entrance)	□	□	□	□	□

6. What do you think is the most critical lighting issue in Shipai Village? (Single choice)

□ Need to turn on lights indoors during the day

□ Unable to see clearly when walking in dimly lit alleys

□ Lack of public spaces for sun exposure and activities

□ Some areas are too dark while others are overly bright

□ Other ______

7. To what extent does lighting condition affect your daily life? (Single choice)

□ Severe impact (e.g., mood depression, vision decline, unwillingness to go out)

□ Significant impact (e.g., frequently needing to turn on lights, feeling uncomfortable)

□ Moderate impact (some inconvenience but acceptable)

□ Almost no impact

III. Space Usage and Health Perception

8. Which outdoor spaces do you use most frequently? (Multiple choices allowed)

□ Along main streets □ Narrow secondary alleys □ Square in front of ancestral hall/temple

□ Scattered small open spaces/squares □ I rarely engage in outdoor activities

9. During the daytime, are you willing to spend more time in well-lit outdoor spaces (e.g., small squares, open streets)? (Single choice)

□ Very willing □ Somewhat willing □ Neutral □ Somewhat unwilling □ Completely unwilling

10. In your opinion, which aspects are most important for good natural lighting? (Multiple choices allowed)

□ Improving mood □ Saving electricity costs □ Ensuring walking safety

□ Promoting neighborhood interaction □ Supporting outdoor activities

□ Maintaining circadian rhythm (sleep, mental) health □ Other ______

IV. Willingness for Renovation and Suggestions

11. If renovations were to take place, which measures to increase lighting would you most like to see implemented? (Multiple choices allowed)

□ Install reflective panels or mirrors in alleys to direct sunlight into deeper areas

□ Demolish a few severely light-blocking buildings to create small open spaces for sunlight and ventilation

□ Utilize some rooftops by converting them into public gardens or centralized drying areas

□ Assist in renovating houses, such as adding skylights or enlarging windows to brighten indoor spaces

□ Other ______

12. To achieve better natural lighting and public activity spaces, minor modifications may be needed to non-structural, non-load-bearing elements (e.g., awnings, partition walls, unauthorized structures). What is your attitude toward this?

□ Strongly support □ Somewhat support □ Depends on the situation

□ Somewhat oppose □ Strongly oppose

13. Are you willing to participate in follow-up community renovation discussions or opinion surveys? (Single choice)

□ Very willing □ Somewhat willing □ Neutral □ Somewhat unwilling □ Completely unwilling

14. Other suggestions (open-ended):

____

Thank you for your participation!