A Study of Environmental Adaptive Transformation Strategies for Patios in Huizhou Architecture

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Abstract

Huizhou architecture, as a representative example of traditional Chinese dwellings, embodies a Patio style with quadrangle dwellings as its core. The Patio serves multiple functions, including ventilation, lighting, drainage system, and fire prevention. It symbolizes the accumulation of wealth and communicating with nature, making it a vital element of green building in Huizhou residences.

The patio in a Huizhou residence is taken as the object of study in this paper, employing on-site observation and questionnaire survey methods. From the aspects of ventilation, shading, as well as daylighting, this paper quantitatively analyzes the significant role of the Patio in the regulation of the internal micro-environment of Huizhou residential houses, particularly the inherent characteristics of heat insulation in summer and warmth in winter. Besides, the objective of this paper is to contribute to the comprehensive study of The Impact of Traditional Chinese Green Architecture on Modern Habitation: A Case Study of Huizhou, Anhui Province. And consequently, the paper is divided into four sections: ○1 Environment and traditional architectural features of the Huizhou area; ○2 Analysis of the influence of courtyards on the micro-environment of Huizhou dwellings; ○3 adaptive renovation measures for courtyards;○4 in the conclusion, this paper presents suitable renovation measures for courtyard renovation to meet the contemporary people's environmental demands of wind, light, heat, water, and humidity, and further explores the ecological strategy of the traditional courtyard, with the aim of enhancing the regional living environment.

Keywords: Patio, Huizhou Architecture, Green Architecture, Patio Renovation

1) Introduction

The Huizhou region refers to the area south of the Yangtze River in Anhui Province, China, including Yixian, Shexian, Xiuning, Qimen, Jixi, Wuyuan, and the Pan-Huizhou region (Fig.1) The outline of Huizhou architecture suggests a particular style of architecture with distinctive regional characteristics, which is primarily characterized by reinforcing Confucian ethical and moral order, which sprouted and formed in the Huizhou Prefecture of the Qing Dynasty (Yongchun, 2005: 2) (Fig.2). Besides, the spatial organization of Huizhou architecture is in the form of a courtyard with the patio as the core, which serves as a channel for the intermingling of indoor and outdoor spaces and is likewise conducive to light and ventilation, a reflection of the wisdom of Huizhou craftsmen in the building. Nevertheless, as the inhabitants' level of life rises, the traditional architecture of Huizhou can no longer suit the needs of contemporary people. For the purpose of obtaining a comfortable living environment, the traditional Huizhou architecture can be converted to habitable, with the intention that it can retain the wisdom of traditional architecture while complying with the requirements of a modern comfortable living environment.

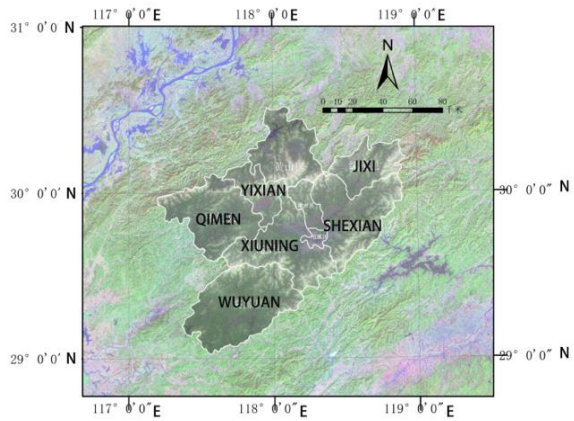


Fig.1 Political Map of Huizhou

Photo source: Zhang Min (2021)

Fig.2 Huizhou architecture

Source: Taken by author

2) Natural and Cultural

2.1 Characteristics of the natural environment in the Huizhou area

2.1.1 Diverse terrain, beautiful mountains, and waters

With minimal flat terrain, the Huizhou region is surrounded by mountains and hills. Moreover, the mountainous terrain accounts for approximately 90% of the terrain in Huizhou. Furthermore, Huizhou is the birthplace of the Xin'an River, and the majority of the significant rivers belong to the Xin'an River system, the 373-kilometer-long mainstream enters the western portion of Zhejiang Province from the east. In this specific geographical environment, Huizhou dwellings were selected with particular attention to preventing

harm and utilizing the terrain and the natural water system intelligently, mostly built against the mountains and water, sitting north and facing south in order that they could get sufficient sunlight and also employ the natural water system for your benefit.

2.1.2 Warm and moist, four distinctive seasons

Huizhou boasts a subtropical humid monsoon climate renowned for its copious rainfall, with an annual precipitation ranging from 1100 to 2500 mm. Notably, approximately 60% of this rainfall is concentrated during the months of May to August. The region enjoys a moderate average annual temperature that ranges between 15.5℃ and 16℃. What sets Huizhou apart is its absence of scorching summer heatwaves or bone-chilling winters, offering a climate characterized by a harmonious balance between warmth and coolness (Yongchun, 2005: 4). Besides, the doors of Huizhou dwellings are oriented to the north and face south, and the north wall is either inaccessible or has a small door, which is an adaptation to the astronomical conditions of the northern hemisphere and the climatic conditions of the monsoon zone in China, which is likewise conducive to light, cold and heat. In the summer, the sun's height angle is high when the doors face south. Hence, the room is not efficiently irradiated, preventing an increase in indoor temperature, whereas in winter, the sun's altitude angle is slight, accordingly, the sun can shine indoors, which increases the temperature of the room. In the summer, the climate in Huizhou is further enhanced by the favorable southeast wind that permeates the rooms. This, combined with the presence of patios or back doors, creates a channel for the passing breeze, effectively dispelling dampness and providing relief from stuffiness and heat. On the other hand, the north wall of the buildings typically does not have doors or features small openings. This design is advantageous during the prevalence of cold north winds in winter, as it prevents the entry of intense cold drafts and facilitates the retention of indoor warmth.

According to the geographical characteristics of Huizhou, the patio fixes the issue of excessive vertical extension and slow drainage of the tile surface of the large-volume building as well as shortens the longitudinal extension of the tile surface, which has a solid inward spitting function, and eliminates the hassle of inadequate indoor ventilation and light conditions due to the large volume, in order that the interior can effectively disperse moisture, ventilation, light as well as receive sunlight (Fig.3).

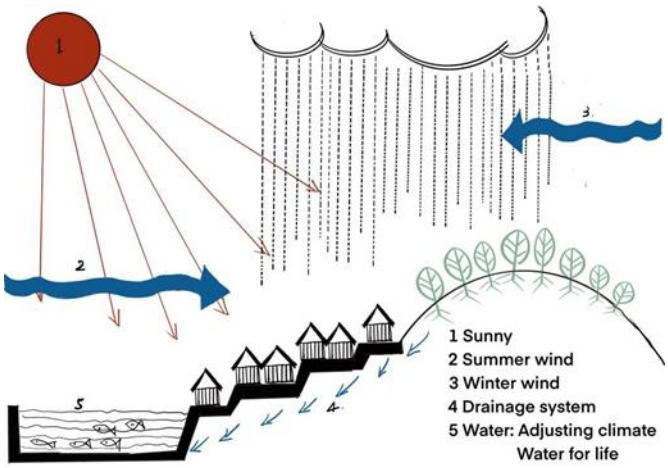


Fig.3 Ecological environment diagram of Huizhou region

Source: Drawled by author

2.2 The Regional Cultural Characteristics of the Huizhou Region

2.2.1 The Influence of Confucianism

Huizhou is the origin of "Neo-Confucianism of Cheng-Zhu," and Zhu Xi's notion of ethics and morality has inspired all elements of Huizhou, including its architecture. Among them, the core idea of Confucianism is the "ritual" system. Confucianism promotes the notion of impartiality's middle ground and non-destructiveness, which is reflected in the layout of architecture. Moreover, the plan structure of Huizhou architecture is mostly inwardly square with full or semi-enclosed shape, with large volume, utilizing the center axis of the room as the axis of symmetry, and the rooms are symmetrically distributed to the left and right, with a side patio in the main hall, front or back garden. Furthermore, the patio is the form of this symmetrical balance, which is "square and symmetrical, left and right balance."

In feudal China, urge women to practice proper etiquette and differentiate between men and women, the Confucius Book of Family Words and Rites suggested that "the height of the palace walls was sufficient to distinguish between the rites of men and women." Particularly, a tall wall was constructed in front of the house to separate men and women. Consequently, the façade of Huizhou buildings was high and confined, which affected the interior's lighting and ventilation, and consequently the patio's emergence was an excellent solution to this problem (Fig.4).

Fig.4 Facade of Huizhou architecture

Source: Taken by author

2.2.2 The Influence of the Hui Merchants

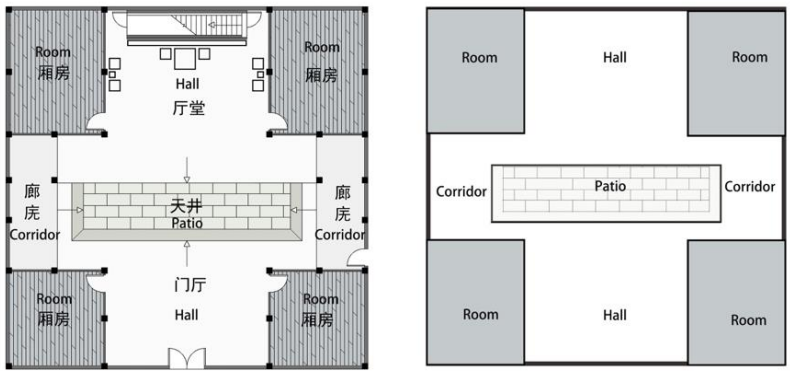
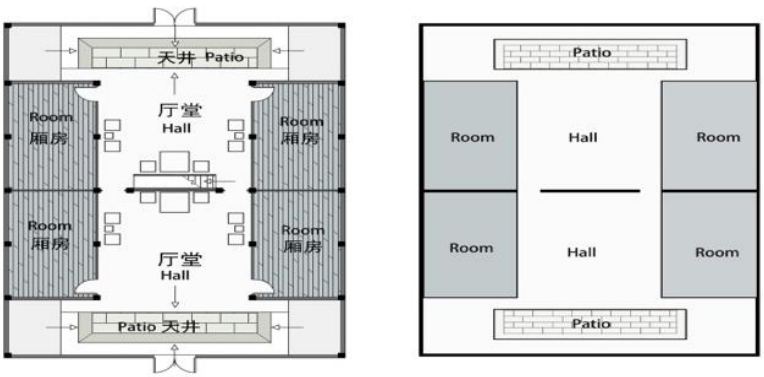
Huizhou architecture, constructed in the Southern Song Dynasty, has a long history, and its formation is closely related to the prosperity of the Huizhou merchants. The fact that Huizhou is located in a mountainous region that is unsuitable for agriculture forced the residents of Huizhou to seek employment elsewhere. And subsequently, having accumulated a large amount of wealth through proper management, in order to respect their ancestors and demonstrate their financial prowess, the Huizhou businessmen spent a great deal of money erecting residences and gardens at home. The merchants were the 'patrons of the arts' of Huizhou architecture, and their aesthetic interests substantially influenced the shaping of Huizhou architecture (Yongchun, 2005: 11). Additionally, In Huizhou, it was customary for men to embark on business endeavors around the age of 14, while women and children typically remained at home. Consequently, for the sake of security, Huizhou architecture featured elevated walls and the absence of frontal windows, necessitating reliance on courtyards for internal illumination and ventilation.

2.3 The traditional architectural features of the Huizhou area

Due to the particular natural environment, in Huizhou, the area of land used for building dwellings is limited, and the city's architectures are small. Huizhou houses are generally approximately 10 meters wide, with three openings, and the depth usually varies, with some reaching over 20 meters. The deeper buildings are primarily divided into two or three houses, each with a patio, which is a closed inner courtyard formed around the patio by elements including compartments, doorways, and corridors. This courtyard's layout is "concave," also recognized as the "three-room pattern," with an additional six rooms located upstairs. There are two rooms next to a hall, and through the combination of the fundamental triple courtyard, the patio can be adjusted to give a variety of distinct structures of dwelling. Furthermore, the

common forms of the floor plan are "concave" （凹）, "return" （回）, and "H". The symmetrical composition of the patio area requires two fundamental conditions to be met: first, the symmetry of the patio space in the two-dimensional plan; and second, the symmetry of the patio space in the three-dimensional space; secondly, the symmetry of the patio in the three-dimensional space, including the building elements and landscape elements, and until that point, the patio space is not symmetrical (Rui et al., 2021: 39) (Table 1).

Table 1 The plane form of Huizhou residential buildings

Plan of the building	Plane distribution diagram
"Concave" type“凹” Fundamental type of the triple house courtyard	
"Return" type “回” Parallel design, horizontal splicing of residential units	
"H" type Tandem design, vertical splicing of residential units	

3) Methodology

The Chinese phrase for "patio" is derived from ancient Chinese texts and originally referred to a landscape with a high perimeter and a low center. From an architectural point of view, a patio refers to the open space enclosed between dwellings or between dwellings and walls (Yiqing, 2020: 4). The area is called a patio due to the fact that it is petite and surrounded by taller houses, resembling a deep well (Kunlun & Ying, 2013: 34-36). As a prominent climate-adaptive design method in traditional Huizhou dwellings, the patio accommodates the functions of daily life and adjusts the indoor environment. Green architecture entails incorporating eco-friendly materials throughout the entire process of designing, organizing, manufacturing, and constructing a building. Its primary objectives are to optimize resource conservation, promote environmental preservation, and fulfill the living requirements of individuals, all while minimizing ecological pollution. A building with a green and healthy meaning is a symbolic concept that is designed and built under the premise of protecting the natural environment for the purpose of maintaining the ecological balance of nature and promoting the harmonious development of man and nature. Residents are placing greater demands on their living environment as urbanization continues to accelerate. In this context, as mechanical cooling and heating systems become more prevalent, the significance of the central purpose of courtyards in contemporary residential buildings is gradually diminishing, and in some cases, even disappearing altogether.

4) Study results

4.1 Environmental Performance

4.1.1 Ventilation and wind protection

Huizhou dwellings boast an open interior design, where halls and chambers seamlessly connect to the courtyard, devoid of walls, partitions, or other obstructions. This layout promotes excellent air circulation and facilitates efficient thermal pressure ventilation, resulting in a notable "chimney effect" that accelerates the exchange of air between the indoors and outdoors (Fig.5). In the hot summer months, the indoor air temperature rises when the sun shines and the hot air rises, and as the patio removes the indoor heat from the outdoors, coupled with the dampness of the patio as well as the low heat absorption coefficient of the stone floor, the convective breeze is cooler and can significantly cut summertime indoor temperatures. Moreover, measurements and interviews with residents indicate that during the warmest months of summer, the outdoor temperature is around 33-37 degrees, whereas the indoor temperature with a patio is around 30-34 degrees (Fig.6). In the winter in the Huizhou region, the high walls that surrounded the patio repelled the cold winds. Despite the fact that it acts as a windbreak, It does not fulfill the requirements for thermal comfort, which is one of the major disadvantages of the patio.

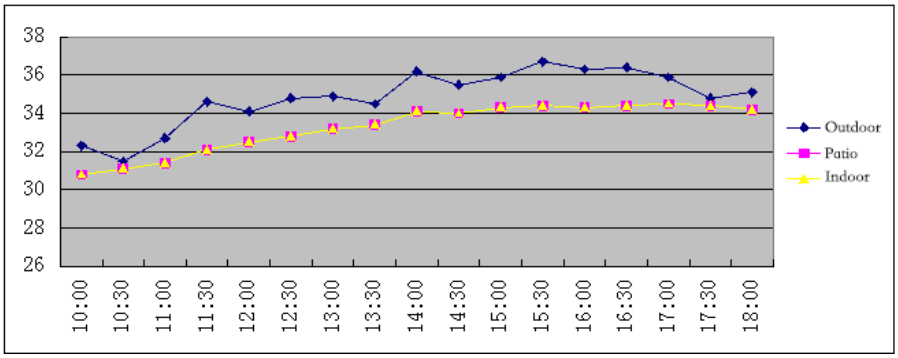


Fig .5 Indoor and outdoor temperatures

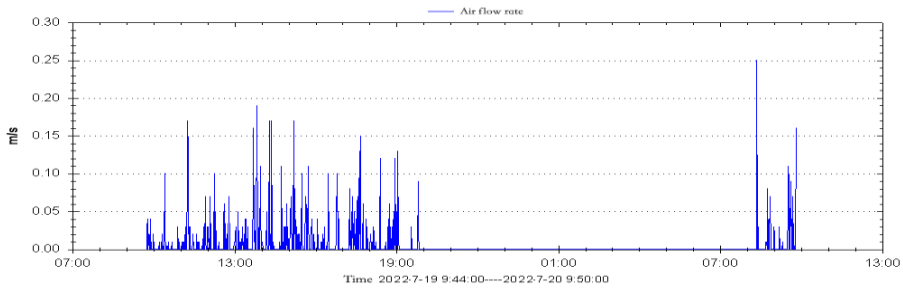


Fig .6 Time variation of wind speed

4.1.2 Sun Shading and Heat Insulation

The geographical coordinates of the Huizhou region lie between approximately 29°31′-31°N and 116°31′-119°45′E. Summer is hot and winter is cold, with an average annual temperature of 15-16℃. The height of the patio is about 10 meters. During summer, direct sunlight struggles to reach the lower section of the patio, except at midday. Simultaneously, the air within the patio becomes heated by the sunlight and steadily rises, leading to the constant influx of colder, less dense air from both sides to replenish the patio. This establishes an air convection pattern between the interior and exterior, facilitating the entry of cold air at the bottom of the patio and effectively lowering its temperature. In winter, the temperature inside the patio is higher than outside, on the condition that the less dense hot air rises, whereas the cold air outside the house then enters the patio, generating convection within and without the patio, contributing to a large amount of heat transfer from the patio to the outside of the house. Additionally, the sun's altitude angle is low in winter, preventing the sun's direct rays from reaching the bottom of the narrow, deep patio. This results in a cold and gloomy climate inside the patio in winter, making it challenging to satisfy people's needs for thermal comfort (Fig.7).

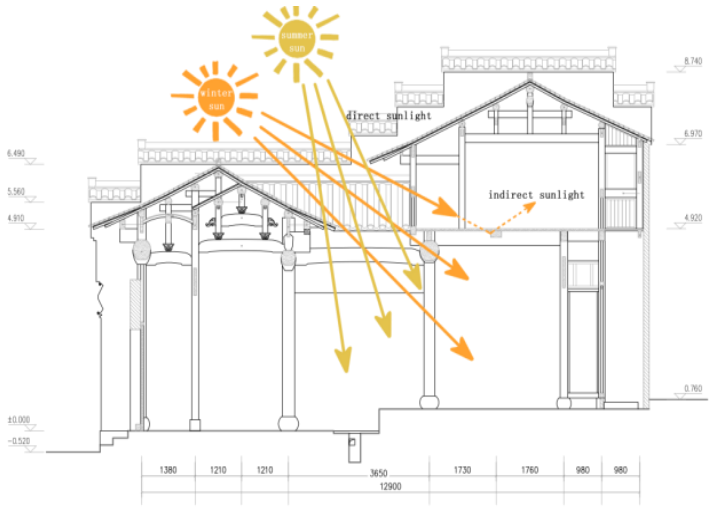


Fig.7 Diagram of solar exposure in winter and summer

Photo source: Drawled by author

4.1.3 Drainage system

In Huizhou villages, the drainage system is also linked through patio space. Besides, the patio is generally divided into two construction forms: one is the gutter-type patio space (Fig.8). The ground beneath the patio area is typically around 30 cm wide and partially sinks to make a drainage ditch. The eaves around the patio incline inward. Except for that, the rainwater is drained unorganized through the roof tiles, and the eaves water flows vertically into the lower concave drainage ditch, which is commonly recognized as "Four Waters to the Church". Concerning design, The drainage ditch has shadowy channels that connect to the exterior and the village's river, allowing for the timely release of rainwater. Some residents keep turtles in their pools for the purpose of preventing silt from blocking the drains. In traditional Chinese culture, the turtle symbolizes longevity and beauty. Another notable feature is the pool patio space (Fig.9). This type of patio itself is a pool, with functions including water storage, drainage, and fire protection, and can also be adopted as a central landscape. Due to the fact that the air below the patio is damp and sunny, Huizhou residents will plant low shrubs and bonsai on the patio, which can Eenhance the environment and alter the temperature and humidity levels inside.

Fig.8 The drainage of the patio

Fig.9 The drainage of the patio

4.1.4 Fire protection

Wood is the predominant building material of Huizhou dwellings. Although wood is green and environmentally friendly, it is easy to cause a fire. Accordingly, preventing fires is what buildings in Huizhou must do. “Ma Tau wall” is the structure that resists the spread of fire outside the building, while the patio is the structure that protects the interior of the building from fire. Furthermore, Huizhou architecture has a progressive hierarchy, with each house separated by a patio for the purpose that even if one house catches fire, it will not expand to additional regions. The patio's heat and smoke extraction to lessen the chance for smoke to accumulate inside (Fig.10).

Fig.10 Fireproofing function of patio

4.2 A questionnaire survey on the comfort level of old and new residential houses in Huizhou in winter and summer

The authors conducted questionnaires and field research on inhabitants between the ages of 20 and 60 in the Huizhou region during the winter of 2021 and summer of 2022, obtaining 21 valid questionnaires, of which 57.14% were living in new self-built residences without patios. Moreover, 95.24% of residents consider that the indoor lighting effect and indoor ventilation effect of buildings with patios are superior (Table 2). Nevertheless, 90.48% of the residents still think that the patio has a poor heat preservation effect, contributing to cold winters and wet summers (Table 3). These are the disadvantages of dwelling with a patio. Based on the survey, the most comfortable seasons of the year in the Huizhou area are in spring and autumn, when the temperature is mild. Nevertheless, due to the larger air humidity, the patio fully satisfies the need for internal ventilation, which is of greater significance. Nevertheless, the adaptive architectural renovation design in summer and winter is more urgent to meet people's requirements for enhancing the quality of life. 71.43% of the residents are willing to spend 100-500 thousand yuan to improve the existing living environment.

Fig.11 Old residential house

Fig.12 New residential house

Table 2. What do you think are the advantages of buildings with patios?

Options	Total	Percentage
Good indoor lighting	20	95.24%
Good indoor ventilation	16	76.19%
Flowers and plants can be planted in the courtyard	15	71.43%
Cool in summer	17	80.95%
High security	9	42.86%
Effective Sampling	21	

Table 3. What do you think are the disadvantages of buildings with patios?

Options	Total	Percentage
Damp	14	66.67%
Poor heat preservation effect	19	90.48%
Poor safety	0	0%
Poor sound insulation	4	19.05%
Effective Sampling	21	

The following conclusions can be deduced from the results of the questionnaire:

A: Huizhou residents are basically satisfied with the lighting and ventilation in the courtyard.

B: For the Huizhou patio, the environmental conditions of wetness and low heat retention must be remedied.

5) Discussion

5.1 Adaptability Improvement Measures for the Patio of Huizhou Residential Buildings in Summer

5.1.2 Principle of patio cooling

The Huizhou patio is high and narrow, with a chimney-like design. As the doors and windows of the rooms open inwards in the building, there is air convection between the terrace and the hallways and chambers. In summer, except at midday, it is challenging for the sun's rays to instantly reach the bottom

of the patio. As a result of the principle of hot air rising and cold air sinking, hot air rises beneath the sunlit patio. The cold air, which is less dense on both sides, is constantly replenished to the patio, forming a convection of air between the interior and exterior, enabling cold air to enter the bottom of the patio, thus reducing the ambient temperature around the patio. Moreover, there are frequently pools and wells inside the patio. In the summer, the evaporation of water will also remove a significant amount of heat, reducing the ambient temperature and increasing the relative humidity of the area within the patio, thereby managing the temperature and relative humidity of the air within the patio (Fig.13).

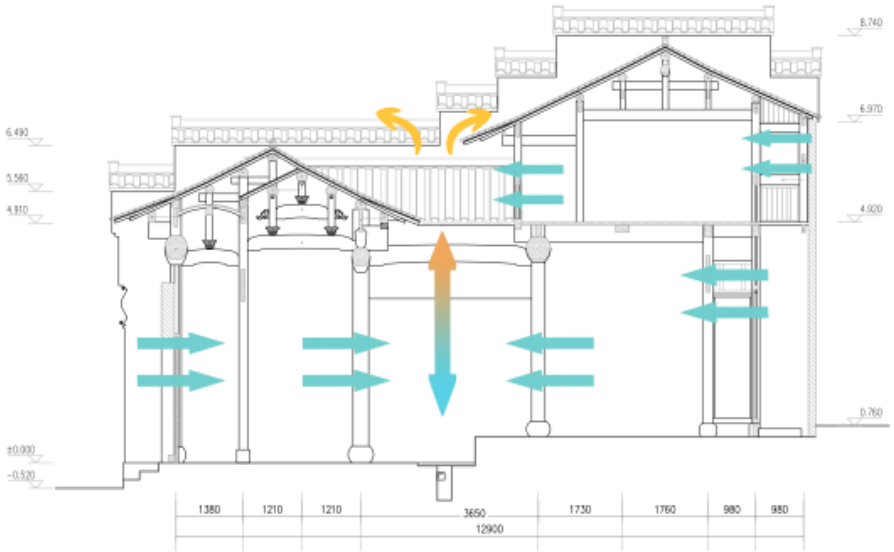


Fig.13 Diagram of the "chimney effect" in the patio

Photo source: Drawled by author

5.1.2 Patio shading retrofit measures

Summers in Huizhou can be warm, consequently, to achieve the purpose of shading and insulating the patio in summer, the reconstruction should obstruct the harsh rays of the sun in summer as well as not affect the principle of airflow in the "chimney effect". For this reason, it is possible to take into consideration movable shade, which refers to the installation of an openable shading curtain above the patio. The sunshade screen can be utilized in the transformation, which can block sunlight radiation, control the amount of visible light based on the material selection, prevent ultraviolet rays, and avoid the interference of glare. Furthermore, it can also be opened and closed and can be modified in any way desired according to the change of sunlight. The sunshade might be composed of air-permeable fiber materials or a louver sunshade so as not to impact the ventilation effect. In the evening, the sunshade can

be closed, and the cold air outside can subsequently enter the patio, which will not affect people's cooling. For ease of use, the electric device can be used and the remote control can be employed to open and close the sun blind (Fig.14).

Fig. 14 Patio with electric awning

Photo source: Drawled by author

Fig.15 Residents in Huizhou use fire buckets to keep warm.

Photo source: Taken by author

5.2 Reconstruction measures for winter adaptability of residential patio in Huizhou

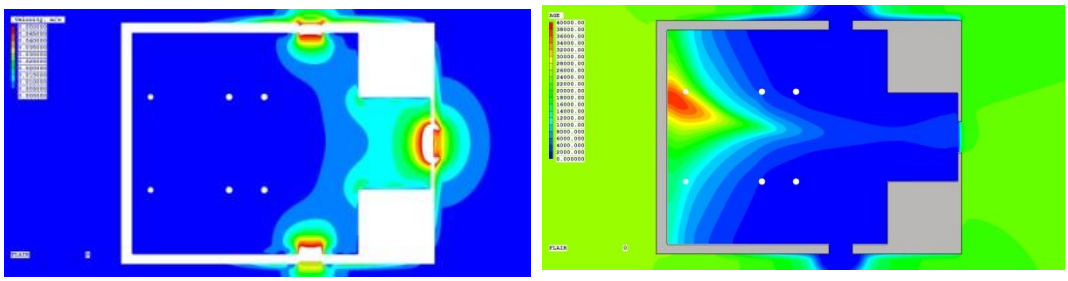
During the winter season, the residential buildings in Huizhou are characterized by cold and humid interiors, making it difficult to meet people's expectations for indoor warmth and comfort. The traditional form of warmth for Huizhou residents is active heating, including the use of fire barrels (Fig.15). As is illustrated in the picture, a charcoal fire is installed inside the barrel, and people use the barrel for warmth. Whereas this form of heating is practical and efficient, it also has downsides. In the first place, burning charcoal in the barrel will produce a great deal of carbon dioxide, which is not conducive to environmental protection and health.

The passive indoor insulation measures on the basis of the patio predominantly include the following three aspects: First, reduce the heat loss caused by the opening of the patio; Second, prevent cold air from entering; Third, the utilization of solar energy. In order to solve these three issues, a sloping glass canopy over the patio can be adopted. The long wave radiation of sunlight will pass through the glass to reach the patio, which will increase the temperature in the patio. Moreover, the external radiation of hot air is mainly short-wave radiation, which is challenging to pass through the glass, in order that the hot air will not be lost easily, and the air circulation will be interrupted by the glass top, thus enhancing the warm keeping performance in the patio in winter. The glass-roofed patio functions similarly to a greenhouse, isolating cold air from the exterior and preventing winter precipitation and snow from entering,

keeping the interior dry and preventing the ground from freezing. As the glass roof absorbs the heat of sunlight, the heating under the patio is transferred to the surrounding rooms to Raise the temperature of the space, which can suit people's requirements for comfort (Chuan et al., 2004: 32).

To demonstrate this scenario, the authors employed Phoenics software to simulate the indoor wind velocity flow with the patio fully enclosed. As seen in the diagram, under normal outdoor winter wind conditions, the indoor wind speed at 1.5 m height is in the range of 0-0.05 m/s, the wind speed around each hole is in the range of 0.015-0.05 m/s, and the wind speed in all other areas is below 0.015 m/s; the air age value at 1.5 m height indoors is in the range of 0-4000s, save for a three-meter radius surrounding the hall towards the southeast wall, where the air is stagnant. Moreover, the age of the air at 1.5m height in the room is within the range of 0 to 4000s, except for the hall near the southeast wall within 3m, all other areas are within 4000s.

The simulation results indicate that the indoor flow speed is slow on the condition that the patio is closed. On one hand, it is due to the small wind speed entering the entrance. On the other hand, The limited opening area of the building could be more beneficial to enhancing inside ventilation, as it is difficult to produce drafts, which is beneficial for improving indoor comfort in winter.



(a) (b)

Fig.17 Wind speed and air age at the height of 1.5m

Photo source: Drawled by author

5.3 Drainage system in the reconstruction of Huizhou dwellings

Due to the heavy spring and autumn rainfall in Huizhou, The rainwater runs from the sloping eaves on all sides of the roof into the open ditch or the dark ditch of the bright hall beneath the patio. Moreover, there is a blind ditch below the patio, which is linked to the outdoor water system to transport the indoor rainfall outside. In case of a rainstorm, the drainage pressure of the underdrain will increase. Rain and snow will cause the hall to get damp and uncomfortable due to the patio's direct connection to the room. Hence, these contradictions should be alleviated during the transformation. To lessen the impact of rain and snow on the building, water diversion pipes are installed around the roof to transfer precipitation to the ground. And the sloped roof with glass over the patio likewise facilitates the collection of rainwater, which enters water pipes that connect to a dark trench and drain instantly to an outdoor pond. The patio's awning can help prevent the intrusion of precipitation and snow (Fig .18)

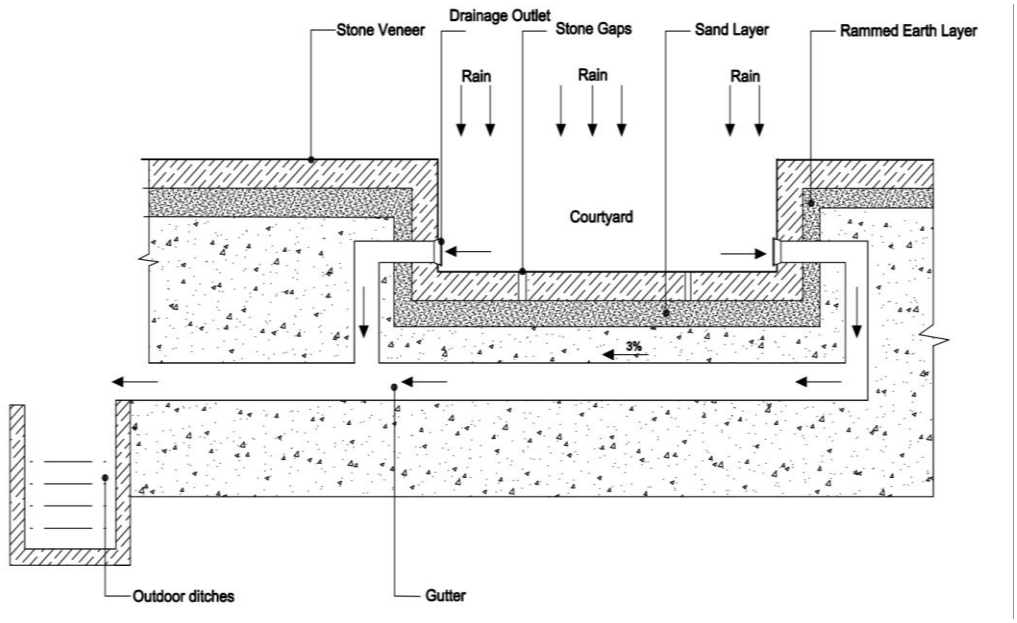


Fig.18 Diagram of the rainwater cycle in the Huizhou patio

Photo source: Drawled by author (2022)

6) Conclusion

The wisdom of ancient craftsmen and ordinary people is undeniably embodied in traditional architecture, which encompasses construction techniques with great regional features that remain applicable in modern architecture (Ping & Fangyan, 2014: 60-63). Within this context, the patio plays an essential role in regulating the microenvironment in Huizhou dwellings. Its creation is rooted in a comprehensive synthesis of natural climate, geographical surroundings, and humanistic ideologies. From the aspects of ventilation, wind prevention, sun shading, heat insulation, lighting, sun absorption, transition space, drainage system, as well as fire prevention, it is analyzed that the construction of patio space serves a certain function in managing and optimizing the environment and climate around the building. On the basis of the field mapping and questionnaire surveys, it is demonstrated that the disadvantages of the patio space are primarily heat in summer, humidity in spring and autumn, as well as the poor thermal insulation and warmth in winter. In combination with people's requirements for living comfort, numerous strategies are proposed to renovate the comfort of the patio to accommodate people's environmental expectations for wind, light, heat, water, and humidity, and to enhance the regional human living environment.

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