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Optimization Strategy for Passive Form Design of Architectural Grey Space under the Background of Climate Adaptability

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Abstract Taking the bottom grey space with great influence on outdoor thermal comfort as the research object, this paper summarizes the morphological characteristics and climate response methods of two types of bottom grey space: overhead grey space and canopy grey space. The spatial form indexes that greatly affect the ecological performance of architectural grey space such as ventilation, shading, etc. are discussed, and two passive spatial form indexes of spatial scale and location orientation are studied. According to the research of related scholars and literature summary, the optimization strategies for passive form design of architectural grey space based on climate adaptability are put forward, which will provide a reference for the climate adaptive design of architectural grey space, and helps to improve the outdoor thermal environment from the micro scale and create a better living environment.
Keywords Architectural grey space, Passive design, Climate adaptability, Morphological optimization
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Since the 21st century, the increase in carbon emissions has led to enhanced greenhouse effect and increased frequency of extreme weather and climate events. Heat exposure refers to the state in which humans or animals are exposed to high temperature environment for a long time, which will bring a variety of health risks, including heat fatigue, heat stroke and other heat-related diseases, and exposure to high temperature environment can also cause heart, respiratory and even mental system diseases[1].

Passive design refers to the design strategy and method that does not use active air conditioning system in building design and makes the building itself have strong self-adjustment ability and climate adaptability. To alleviate the harm caused by high temperature and heat exposure to the human body, it is necessary to do a good job of personal protection and reduce outdoor activities. Besides, in the field of construction, reasonable passive design can also mitigate the risk of high temperature and heat exposure.

For example, planting vegetation outside or around the building to absorb and reflect partial sunlight can reduce the temperature of surrounding space; or reasonably designing the shape and layout of the building can guide the wind current, improve the air flow, and take away excess heat. Architectural grey space is a common passive design. Due to unique spatial characteristics, it can achieve shading and heat protection and natural ventilation, and also weaken the harm of high temperature and heat exposure to human health.

Through literature review and case analysis, this paper summarizes the form control indexes that affect the ecological performance of grey space buildings, and puts forward the optimization measures for passive form design of grey space, which will provide a reference for the spatial form design of architectural grey space in the future, and achieve the goal of improving outdoor thermal environment, thus reducing the risk of heat exposure, and creating a better urban ecological environment and a better living environment.

1 Morphological characteristics and climate response of bottom grey space

Japanese architect Kisho Kurokawa put

Column introduction

The column "City Observer" is initiated by Yang Xin and Zhang Qi, the hosts of RLncut research station, aiming to observe the city we live in and measure the space we use. Since the 21st century, the increase in carbon emissions has led to enhanced greenhouse effect and increased frequency of extreme weather and climate events. This article focuses on the optimization measures for passive form design of urban gray space, and discusses the way of improving outdoor thermal environment, reducing the risk of heat exposure, and creating a better urban ecological environment and a better living environment.

Yang Xin, Zhang Qi, the hosts of RLncut research station

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forward the concept of “grey space” in his book *Japanese Grey Tone Culture*. He proposed that grey space, as an intercalated space between indoor and outdoor space, is the third domain between inside and outside[2].

There are various types of grey space, including architectural grey space and architectural sketch grey space in terms of different construction methods, overhead grey space and corridor grey space according to different morphological characteristics[3], top grey space, middle grey space and bottom grey space on the basis of different locations of grey space in the building[4]. Both roof grey space and middle grey space have good architectural ecological functions. This paper mainly studies the relationship between grey space and improvement of heat exposure risk in outdoor activities. Since bottom grey space is directly related to the outdoors and is closely related to people’s outdoor activities, it is chosen as the research object.

Bottom grey space usually refers to the grey space located at the bottom of the building. Due to its excellent architectural ecological performance, it has been widely used. Both Mokoshi (a Chinese architectural term referring to the practice of adding a circle of corridors outside the main body of a building) of ancient buildings in China and arcade buildings in the south belong to this type of grey space, which can be divided into overhead grey space and canopy grey space in accordance with the relationship between grey space and main structure of the building (Table 1).

1.1 Overhead grey space

“Overhead” refers to the architectural structure of a house built on stilts. In grey space design, overhead grey space mainly refers to the building area formed by upper architectural form and bottom architectural form due to the contraction of bottom space in the building.

1.1.1 Morphological characteristics. In the bottom overhead grey space, grey space plane is generally located inside the projection plane of the main functional space of the building, which is formed by the subtraction operation at the bottom of the main building. Generally, it may or may not have specific functions. The bottom overhead grey space with specific functions is generally used as a canopy for the entrance to a building, or an architectural veranda (such as arcade space), playing a role of traffic; the bottom overhead grey space that does not have specific functions is generally used as a public activity space between indoor and outdoor spaces.

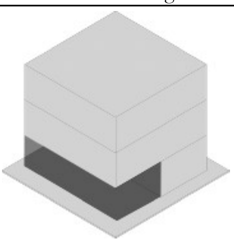
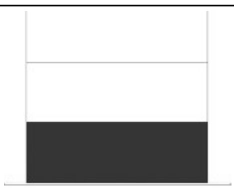
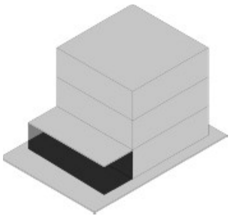
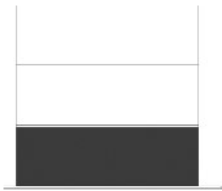
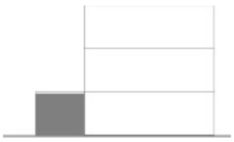
In terms of plane form, there are generally four basic forms: single-sided overhead, two-sided overhead, three-sided overhead and four-sided overhead, and the openness and publicity will increase with the increasing number of overhead surfaces (Fig.1).

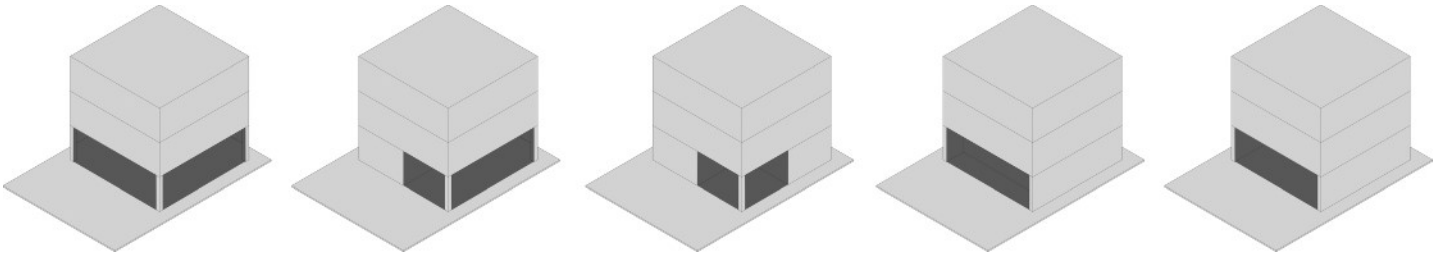
The opening degree of single-sided overhead bottom grey space is generally low and is commonly introverted. The smaller spatial scale can be used as the entrance part of public buildings, and the larger one can be used as the public activity area of public buildings. The opposite two-sided overhead bottom grey space is easy to form natural ventilation due to the action of wind pressure. The grey space open on the two proximal sides is associated with both directions simultaneously, and can generally be used as an entrance space of the building, or an outdoor activity space of public buildings. The three-sided overhead grey space has strong openness and traversability. The four-sided overhead bottom grey space is open to all four directions, with accessibility in all directions and strong openness.

The overhead bottom is easy to form good natural ventilation and large shadow areas, and is suitable for traffic and people’s daily leisure communication while providing the function of shelter from the wind and rain. This type of grey space often permeates with the surrounding environment and has strong urban attributes.

1.1.2 Climate response. The use of bottom overhead grey space in climate design is not a new technique, and has long existed in traditional residential houses in China. Taking the stilted building with overhead bottom in the south as an example (Fig.2), overhead bottom gives the upstair functional space a wide view and can make the lower part of the building ventilated smoothly to adapt to humid and hot climates, and the overhead part at the bottom can be used as an auxiliary room for living. Another example is the arcade building in southern Fujian (Fig.3). Veranda-style bottom overhead space becomes the transition area between the building and

Table 1 Type of bottom grey space

Type of grey space	Axonometric drawing	Front view	Side view
Overhead			
Canopy			



Four-sided overhead | Three-sided overhead | Proximal two-sided overhead | Opposite two-sided overhead | Single-sided overhead

Fig.1 Basic plane form of overhead grey space

the street, creating an urban grey space that can shade the sun and rain, and is suitable for traffic and communication in hot climate.

Therefore, bottom overhead grey space is of great significance for heat insulation in buildings. First of all, as a self-shading of the building, it reduces the body surface area receiving solar radiation at the bottom of the building and reduces the quantity of heat. Secondly, it reduces the sun's angle of incidence, which in turn reduces solar radiation time. In addition, overhead space is also conducive to increasing wind pressure, strengthening building ventilation, and taking away heat. Plating green plants inside overhead space will help regulate the microclimate. The sunshading of grey space profile is shown in Fig.4.

1.2 Canopy grey space

Canopy grey space adopts the operation of spatial addition. It can be the outer grey space of the main structure of the building formed by outward extension of building roof, or the bottom grey space formed by adding building components outside the main structure of the building, generally in the form of canopy or veranda.

1.2.1 Morphological characteristics. Canopy grey space is the lower space area created by the building component canopy, and it is the operation of spatial addition. Grey space is located outside the main functional plane of the building. Architectural canopy is composed of two categories (Fig.5). One is the canopy space at the entrance of the building, which plays the role of marking the entrance, shielding the wind and rain, and transitioning and buffering the indoor and outdoor spaces. The other is the veranda space around the main structure of the building, which plays the role of protecting the main structure of the building, creating a comfortable traffic environment, and enriching the facade of the building.

In terms of planar form, grey space may be located in any part around the main structure of the building if it exists in the form of entrance canopy. If grey space exists in the form of veranda, it may be a form of encircling one or more sides of the main structure of the building, or it can be a combination of the two.

In terms of facade form, the height of grey space can be the full height of first floor or ground floor, or it can be formed by outward extension of the roof or additional components around the building. The opening interface can be supported with or without columns.

1.2.2 Climate response. Canopy grey space is set outside the main structure of the building, and plays a role in shading the building from the sun and rain and guiding ventilation. The effect of shading and rain protection is related to overhang depth, and the greater the overhang depth, the better the effect of shading and rain protection. It is widely used in hot areas.

Generally, adding a canopy grey space on the south side of the building can prevent the indoor temperature increase caused by strong direct solar radiation. Besides, grey space can form a buffer to slow the transmission of outdoor solar radiation to the indoor.

Canopy grey space can meet the demand of shading to a certain extent, but when the solar radiation has a certain angle of inclination, the sunlight can still reach the interior of grey space. At this time, the practice of increasing the overhanging eave of the building can increase the shadow area formed in grey space, and obtain more shade space (Fig.6).

Traditional buildings in China all have abyssal eaves, and the ancients had long realized the use of building eaves to shade the sun. The depth of eaves is generally related to the incidence angle of the sun, which generally ensures that it can block most of the solar radiation when the solar altitude is the maximum in the summer solstice, and make the solar radiation reach the building surface when the solar altitude is the minimum in the winter solstice, thereby regulating the comfort inside the building by adjusting the incident quantity of solar radiation.

2 Optimization indexes for passive form of grey space

The unique spatial form of bottom grey space can naturally shield the sun and form wind pressure ventilation. The transition space formed can also provide air buffer, and reduce the direct intersection of cold and hot air flow in the adjacent functional space. Moreover, it acts as a buffer to the lower space, blocks the sunlight and prevents the temperature rise caused by direct solar radiation.

Grey space form refers to the spatial and visual manifestations of grey space, including appearance, spatial form, technical materials, etc., while the spatial form of architectural grey space refers to the scale of each envelope interface of grey space and the air space formed. At present, few efforts have been dedicated to the influence of microscopic scale such as architectural grey space on outdoor thermal environment. Therefore, in order to facilitate subsequent research and analysis, based on existing research results and theories, the optimization indexes for passive form of architectural grey space are summarized into two aspects: spatial scale and location orientation (Table 2).

2.1 Spatial scale

At the microscopic level of architectural grey space, size and proportion are important indexes of spatial scale, which jointly affect the user's feeling of space. Size indicates the absolute size of spatial form, mainly including height, depth, length, area and other basic indexes.

Proportion reflects the characteristics of spatial form, mainly including special form indexes derived from basic indexes such as length-to-depth ratio (LDR) and height-to-depth ratio (HDR) (Table 3 and Fig.7).

According to the existing research results, there is a certain correlation between spatial scale of grey space and microclimate environment. Dong Binbin[5] studied the wind environment at outdoor pedestrian height of bottom overhead buildings from five aspects: overhead height, overhead width, overhead depth, building height and building length, and found that overhead width and building height had a great impact on outdoor wind environment of bottom overhead buildings. When comparing the thermal environment of inlet transition space at different heights, Zhang Rina[6] found that with the increase of overhead height, the temperature, average radiation temperature and air flow rate all increased, while the relative humidity showed a decreasing trend. Yin Shi[7] studied the relationship between the spatial scale of pavement and microclimate through numerical simulation, and found that affected by solar radiation, the wider the pavement, the better the microclimate could be obtained, while the narrower the pavement, the worse the microclimate.

Considering that there is a certain correlation among different quantitative indexes, height and length are selected as secondary quantitative indexes in this study to explore the influence of grey space on thermal environment under different heights and lengths.

2.2 Location orientation

The change of position orientation mainly affects the thermal comfort of human body from two aspects: wind speed and average radiation temperature. Pearlmutter et al.[8] conducted a more in-depth study on the thermal environment of summer street canyon model under hot and dry climate, and found that the comfort of streets parallel to wind direction was better than that of streets perpendicular to wind direction. Bourbia et al.[9] measured the summer thermal environment of urban street canyon in Bab El–Oued City and found that the temperature rise of

Fig.2 Stilted building

Fig.3 Arcade building in southern Fujian

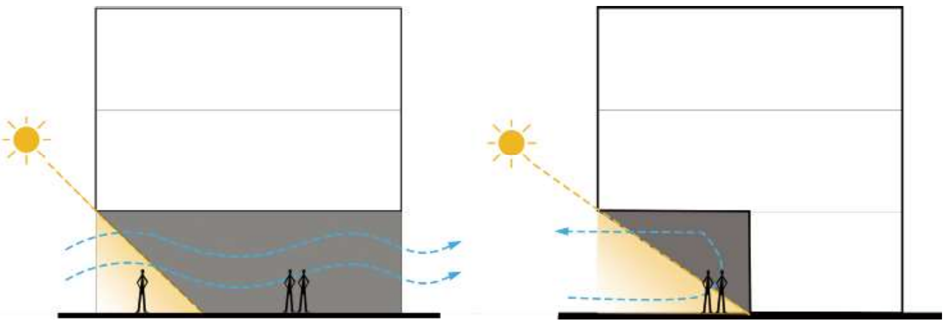


Fig.4 Climate response of bottom overhead grey space

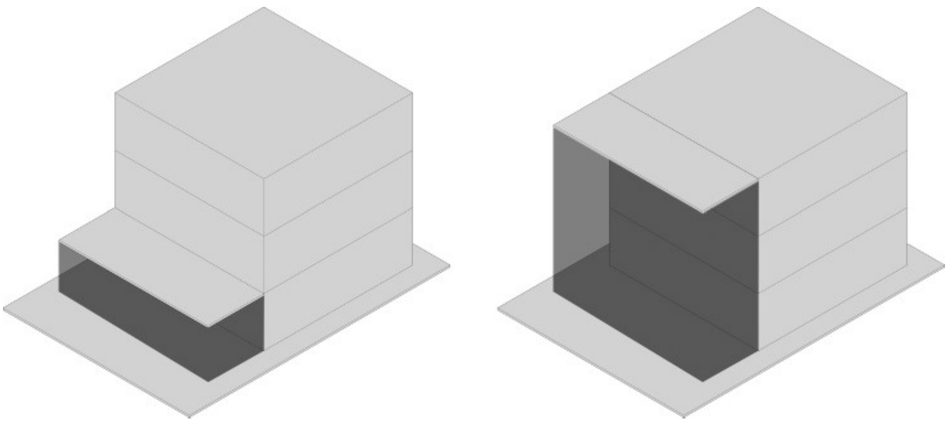


Fig.5 Form of canopy grey space

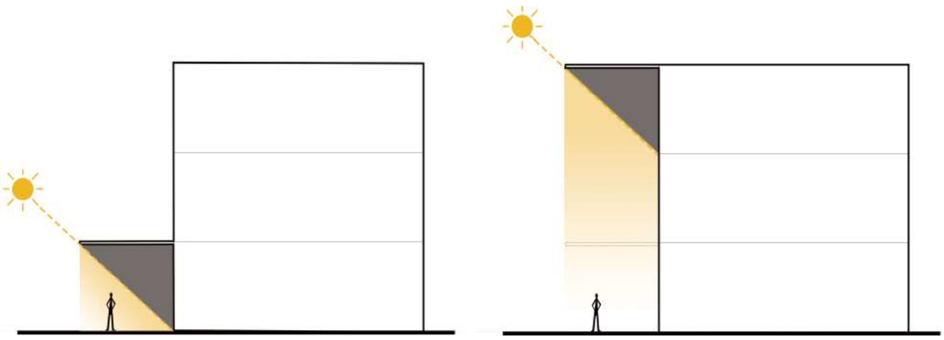


Fig.6 Climate response of canopy grey space

east-west street canyon was more significant than that of north-south street canyon.

In addition to external factors such as street canyon orientation, building orientation and incoming wind direction, grey space is an important medium for heat exchange between buildings and the external environment, and its thermal environment is also affected by location orientation. Location of grey space refers to different directions of grey space in the building, such as south side, north side, east side and west side, while orientation refers to the direction facing the main side interface, such as facing east, west, south and north. Orientation of location leads to differences in solar radiation and natural ventilation in the space. For example, the east-facing porch is subjected to solar radiation from the east side in the summer morning, and absorbs most of the heat, thus forming a thermal insulation effect on indoor functional space, while the west-facing porch can reduce the adverse effects of solar radiation from the west during the afternoon high temperature period. Xue Jiawei et al.[10] found that solar radiation was the main factor affecting the thermal comfort of arcade veranda by comparing summer thermal environment of arcade veranda of different directions in Zhongshan South Road and Xinmen Street in Quanzhou, and the thermal comfort of arcade veranda from high to low were west side > east side > south side > north side.

3 Optimization measures for passive form design of grey space

3.1 Optimization strategies of spatial scale

Spatial scale is the most intuitive and basic three-dimensional spatial quantitative index of grey space, and reasonable spatial scale is conducive to creating a comfortable outdoor thermal environment. Combined with the previous studies, the optimization strategies of spatial scale are summarized as follows.

3.1.1 Height control of grey space. The height of grey space is limited by building height and number of overhead floors, usually manifested as one or two floors, and a few reach three or more floors. The change in height of overhead space mainly affects outdoor thermal comfort through average radiation temperature and wind speed. In summer, with the increase of overhead height, the area of direct solar radiation in overhead area expands, leading to the deterioration of outdoor thermal comfort.

To sum up, in order to improve outdoor thermal comfort in summer, the height of grey space should be controlled as much as possible in spatial scale design to avoid too much direct solar radiation. If a tall overhead space is set at the entrance of the building, green vegetation can be considered to be planted around it to block the direct solar radiation during the high temperature period in the transition season.

In addition, the design of overhead height should also take into account the lighting conditions and atmosphere creation inside the space. When the overhead height is too low, the internal lighting conditions will be adversely affected, and it is easy to cause depressed psychological feelings to users[11].

3.1.2 Length control of grey space. Different from height, the length of overhead space has no obvious rule in its value, and is mainly related to the size of column network and the number of overhead column spans. The variation of the length of overhead space also affects outdoor thermal comfort through average radiation temperature and wind speed. In summer, when the overhead length gradually increases, the shadow area in overhead area expands, the average radiation temperature gradually decreases, and the wind speed will increase slightly as well, creating better outdoor thermal comfort.

In summary, in order to improve outdoor thermal comfort in summer, the overhead length of grey space should be increased as much as possible in spatial scale design to avoid too short overhead space. In addition, the design of overhead length should also take into account the space proportion and practicability. When the length-to-width ratio of space is too large, the linear space is difficult to give people a sense of staying, and too large overhead area is easy to cause space waste.

3.2 Optimization strategies for location orientation

The thermal environment of grey space is related not only to the orientation of building monomers, but also to the orientation of the location of grey space in the building. The sunshine distribution and ventilation of space vary among different orientation locations, which will affect the thermal comfort of human body. The optimization strategies for location orientation are summarized as follows.

In summer, due to large solar altitude, the overhead areas on the east and west sides are easily exposed to direct sunlight in the afternoon, while the overhead areas on the south and north sides are less exposed to direct sunlight. Meanwhile, under the action of prevailing wind, the overhead areas on the north side form a good ventilation path, making the air convection smooth, which is conducive to improving outdoor thermal comfort.

In conclusion, in order to achieve good outdoor thermal comfort in overhead area in summer, overhead space should be set on the south and north sides of the building, while grey space should be avoided on the east and west sides of the building. When overhead area is set in other orientations, other optimization measures can be taken according to overhead locations and seasonal characteristics to improve outdoor thermal comfort, such as planting green vegetation, changing underlying surface material, adding enclosure interface, etc.

4 Conclusions

In this paper, the bottom grey space that has strong correlation with outdoor activities is selected as the research object, and the morphological characteristics and climate response methods of two types of bottom grey space, overhead grey space and canopy grey space, are discussed. The morphological indexes affecting outdoor thermal environment are selected, and further divided into spatial scale and location orientation.

Based on the actual situation, this paper proposes the optimization strategies for passive form design of architectural grey space based on climate adaptability.

(1) The height of grey space should be controlled at about one layer to avoid too much direct sunlight.

(2) The length of grey space should be increased as far as possible within a reasonable range of spatial scale, so as to increase the shadow area and reduce the radiation temperature.

(3) The orientation of grey space should be as close as possible to the south and north sides, and should not be set directly on the east and

(To be continued in P12)

Table 2 Summary of grey space form indexes affecting outdoor thermal comfort

Classification	Secondary index
Spatial scale	Height, length, depth, length-to-depth ratio (LDR), height-to-depth ratio (HDR), overhead area
Location orientation	Location of grey space, orientation of grey space

Table 3 Spatial scale index of grey space

Index	Definition	Formula
Height	Vertical distance from bottom to top of grey space	–
Length	Distance between two ends of main lighting surface of grey space	–
Depth	Distance between grey space and two vertical ends of main lighting surface	–
LDR	Length-to-depth ratio of grey space	LDR = length/depth
HDR	Height-to-depth ratio of grey space	HDR = height/depth
Overhead area	Base area of overhead section	–

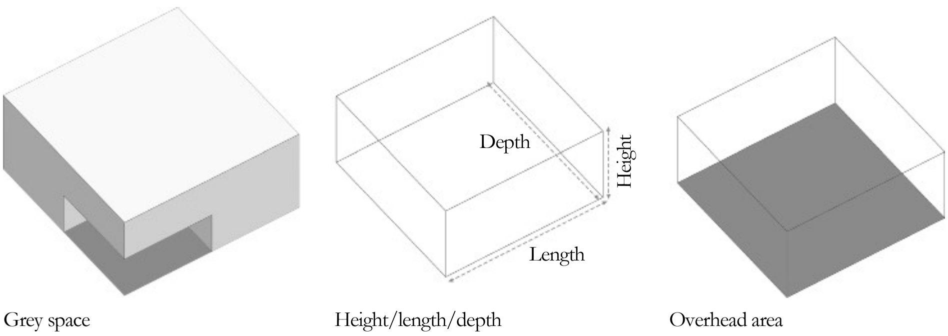


Fig.7 Spatial scale index

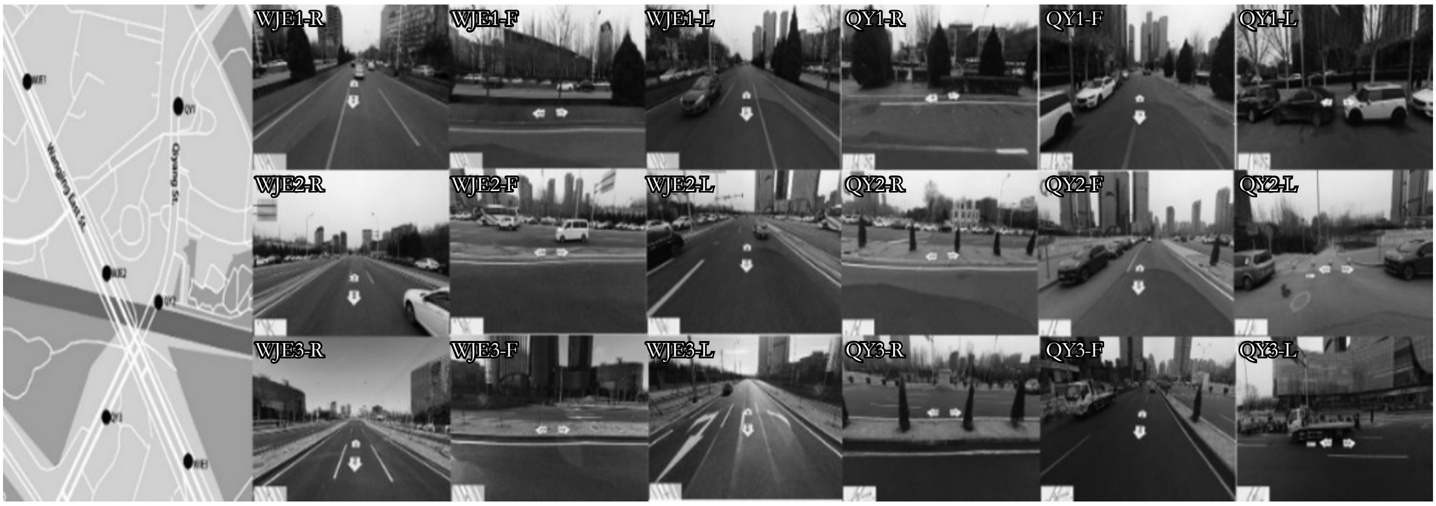


Fig.2 The street view photos of side streets around Wangjing East Station

width ratio of the street is 1.15, which indicates that the street space in this area has a weak sense of closure and is an open space suitable for young women's activities[5].

The streets around Wangjing East Station can create more suitable street spaces for young women groups by improving street accessibility, humanized facilities and integration of leisure and entertainment places from the planning level. Appropriate scale and open and varied space can provide young women with a sense of security and interest. The construction of infrastructure for women cannot be ignored. In addition, because different groups have different preferences for space composition, more efforts should be devoted to meet the space needs of different groups while creating and transforming urban street spaces, so as to create a more livable environment for all social groups.

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(Continued from P5)

west sides.

This paper puts forward the optimization strategies for passive form of architectural grey space based on climate adaptability, and provides a reference for form design of architectural grey space, which is conducive to creating a good outdoor thermal environment and a better living environment.

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