Journal of Landscape Research 2024, 16(3): 1-7

Urban Spatial Form Optimization Strategies Based on the Principle of Climate Adaptability of Regional Architecture: A Case Study of Traditional Cave Dwelling Villages in Northern Shaanxi Province

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Abstract A multitude of climate-adaptive design approaches are embedded in regional architecture, which have a positive impact on addressing the deformed development of urban spatial patterns and the dual challenges of climate and resources. This paper examines the principles of climate adaptability embedded in the site layout and spatial organization characteristics of traditional cave dwelling villages in northern Shaanxi Province. The extracted climate adaptability principles are summarized, and the resulting design strategies that are well-suited to the contemporary urban space form are presented. Through analysis, it can be observed that traditional cave dwelling villages in northern Shaanxi are predominantly situated on south-facing slopes in proximity to water at low altitudes. These villages are characterized by compact building groups and east-west development, which is constrained by the elements of mountains and rivers. A two-level street system is generated, comprising streets parallel to the contour line and roadways perpendicular to the contour line. This results in the formation of a courtyard form enclosed by mountains. Such site layout and spatial organization exhibit excellent climate adaptability with regard to heat, ventilation, and wind storage. In light of the aforementioned considerations, the following urban spatial form design strategies are put forth: ① the topographic height difference can be exploited to obtain sufficient sunshine; ② the group shape can be optimized in order to reduce building energy consumption; ③ the best orientation of the building can be chosen to take account of both winter and summer conditions; ④ the height and length can be combined in order to form natural masking; ⑤ the D/H ratio of streets and roadways should be controlled to achieve a balance between heat gain and cooling of groups; ⑥ vents should be set appropriately to optimize group ventilation; ⑦ climate buffers should be established to increase the level of climate response.

Keywords Traditional cave dwellings in northern Shaanxi, Urban spatial form, Outdoor thermal environment
DOI 10.16785/j.issn 1943-989x.2024.3.001

Since the 21st century, with the continuous progress of science and technology, the ability of human beings to master nature has been significantly enhanced. This has led to a transformation in the architectural construction system, which has evolved into a human-centered "enjoyment of wasteful" system characterized by large-scale consumption of natural resources and large-scale emission of waste pollutants[1]. The layout and morphological characteristics of buildings and cities have been the subject of increasing interest in the field of modeling and the application of new technologies. This has led to the deformed development of urban spatial forms, the intensification of the heat island effect, the frequent occurrence of extreme weather events in cities, and the deterioration of the outdoor thermal environment. These developments have had a significant impact on human physiological health. The utilization of active devices, such as air conditioners,

Column introduction

The City Observer column, initiated by Yang Xin and Zhang Qi, the hosts of the RLncut research station, is designed to observe the city in which we live, to measure the urban space, to reveal the essence behind the appearance, and to explore the source of vitality.

This article examines the cave dwelling villages in northern Shaanxi Province, which exemplify a multitude of straightforward ecological design principles. The elements, including site selection and the layout of traditional settlements, the form and space of individual buildings, and the materials and construction techniques employed, all reflect an objective and detailed knowledge of the regional climatic conditions. By examining the site layout and spatial organization of the cave dwelling village, as well as its exemplary climatic adaptability with regard to heat gain, ventilation, and wind shelter, it is anticipated that these experiences can be applied to urban design with a view to improving the issues currently being experienced in urban spatial development and ecology at the ecological level.

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Received: March 12, 2024 Accepted: May 18, 2024
Sponsored by Beijing Urban Governance Research Base of North China University of Technology (2024CSZL07).
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also results in an increase in carbon emissions, thereby exacerbating the adverse effects of climate change.

The regional architecture of a given area contains a multitude of straightforward ecological design principles, including the site selection and layout of traditional settlements, the form and space of individual buildings, and the materials and construction techniques used. These principles reflect a detailed and objective understanding of the climatic conditions specific to the region in question. It is crucial to investigate the climate-adaptive construction strategies embedded in them and apply them to contemporary urban renewal and design initiatives with the objective of enhancing the outdoor thermal environment of cities.

The traditional cave dwelling village in northern Shaanxi represents a typical regional building group with climate adaptability. By employing a few fundamental ecological principles, humans have created a microclimate that is both comfortable and conducive to life on the Loess Plateau, a region characterized by strong winds and sandstorms. The wisdom of on-site construction can assist us in comprehending the local climate response. The contemporary understanding of their climatic response can also facilitate the achievement of climate-resilient design in the context of current village site selection and layout, as well as urban planning and renewal.

1 Site selection and layout

1.1 Village location

1.1.1 Village location characteristics. Northern Shaanxi, situated in the center of the Loess Plateau in the northern hemisphere of China, is one of the regions with the most severe soil erosion in China. Over time, the landforms have been shaped into tributary gullies, hairy gullies, beam mounts, terrace like plain, and other forms as a result of the long-term erosion of surface runoff. The climate of the region is characterized by pronounced seasonality, with considerable annual and daily fluctuations in temperature, cold and windy winters, and an annual precipitation of less than 500 mm, which classifies the region as semi-arid. In a climate characterized by low temperatures and scarce precipitation, the traditional cave dwellings of northern Shaanxi serve to create a more favorable microclimate, thereby mitigating the adverse effects of the climate through the strategic selection of their location.

A superposition analysis of the distribution of 107 provincial-level traditional cave dwelling villages in Shaanxi Province with data on elevation, aspect, slope, and water-flow buffers in northern Shaanxi reveals that the majority of the cave dwelling villages are situated on hillside slopes with a significant degree of slope (Figs.1–2), and are oriented toward sunny slopes such as the south, southeast, and southwest (Fig.3). The results of the superposition analysis of the water buffer indicate that the majority of cave dwelling villages are situated within a radius of 300 m of the water buffer (Fig.4), demonstrating the overall characteristics of "close to the water but not pro-water".

1.1.2 Climate adaptability principle. The traditional cave dwelling villages in northern Shaanxi are often situated on hillsides with pronounced slopes. From the perspective of climate adaptability, the selection of such sites is also intended to facilitate adaptation to the unique local climate conditions. The frigid winters that typify northern Shaanxi render sunlight a particularly crucial resource.

The solar elevation angle and solar incident angle are significant indicators of the quantity of solar radiation. The solar elevation angle is the angle between the solar rays and the horizon. The solar incidence angle refers to the angle at which the sun shines directly on the ground and is usually expressed as the angle between the solar rays and the ground's normal. It should be noted that the two angles are generally residual to each other (Fig.5). The greater the solar elevation angle, the smaller the solar incidence angle, the smaller the heated area, the more concentrated the light, the more solar radiation energy obtained, and the greater the solar radiation intensity. The smaller the solar elevation angle, the larger the solar incidence angle, the larger the heated area, the more dispersed the light, the less solar radiation energy obtained, and the smaller the solar radiation intensity (Fig.6).

A comparison of the solar elevation angle of northern Shaanxi with that of Xi'an reveals that northern Shaanxi has a relatively small solar elevation angle (Table 1). Despite the expansive area that receives heating, the rays are diffused, resulting in a relatively low level of solar radiation energy and intensity.

However, the traditional cave dwelling villages in northern Shaanxi are situated on hillsides, which not only optimizes land use efficiency but also reduces the solar incidence angle and increases the solar elevation angle in winter, thereby concentrating the light and increasing solar radiation. During the summer months, the increase in solar elevation angle results in the solar rays entering the house primarily from the south, reaching a distance of 1.0–1.5 m from the exterior wall. In contrast, the flat roof and facade of the building are exposed to direct sunlight, while the interior of the cave dwelling remains relatively cool. The strategic placement of traditional cave dwellings, with their proximity to natural sources of shade, contributes to the creation of an optimal indoor-outdoor thermal environment (Fig.7).

In northern Shaanxi Province, the predominant winds are from the northwest and southeast, with high speeds. As a result, it is of great importance for the residents of this region to take precautions to avoid exposure to these winds. The hilly terrain of the Loess Plateau region allows for the generation of local winds, which are a combination of topographical and temperature-related effects, in addition to the prevailing general climate winds (monsoon). These local winds play a significant role in shaping the local microclimate of traditional cave dwelling villages. Leeward slope areas and eddy wind areas on hillsides backed by northwesterly winds are typically regarded as favorable locations for providing protection against the prevailing cold northwesterly winds (Table 2). The analysis of satellite images of typical cave dwelling villages revealed that traditional cave dwelling villages in northern Shaanxi are predominantly situated in the leeward slope area and eddy wind area on the sunny side of the mountain slopes.

In the formation of wet environments, traditional cave dwelling villages in northern Shaanxi are predominantly situated in proximity to water sources. The presence of rivers in these settlements not only provides a source of cooling but also facilitates the maintenance of optimal humidity levels. In contrast, topographic relief impedes the dissipation of spatial relative humidity. Slopes are either perpendicular or at an angle to the dominant wind direction, which is southeast. Consequently, windward slopes can create a favorable humidity environment in all seasons.

In conclusion, the traditional cave dwelling villages in northern Shaanxi exemplify a straightforward climate-adaptive design principle for the local climatic environment. This principle enables the creation of an optimal indoor and outdoor thermal environment, taking into account the three key factors of heat, wind, and humidity.

1.2 Layout patterns

1.2.1 Layout morphological characteristics. The layout of traditional cave dwelling villages in northern Shaanxi can be broadly categorized into three types based on the relationship between villages and water sources. These types

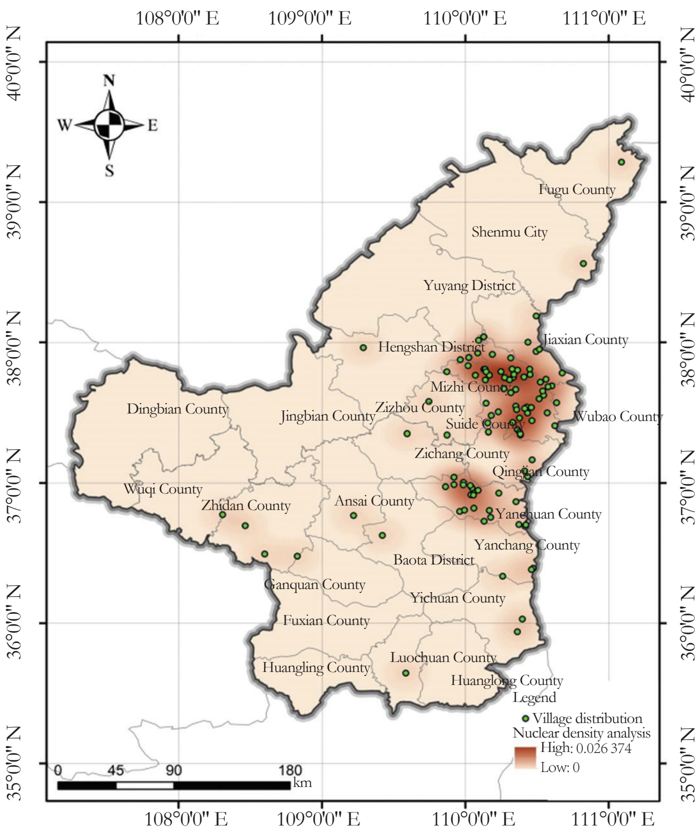


Fig.1 Distribution of cave dwelling villages in northern Shaanxi Province

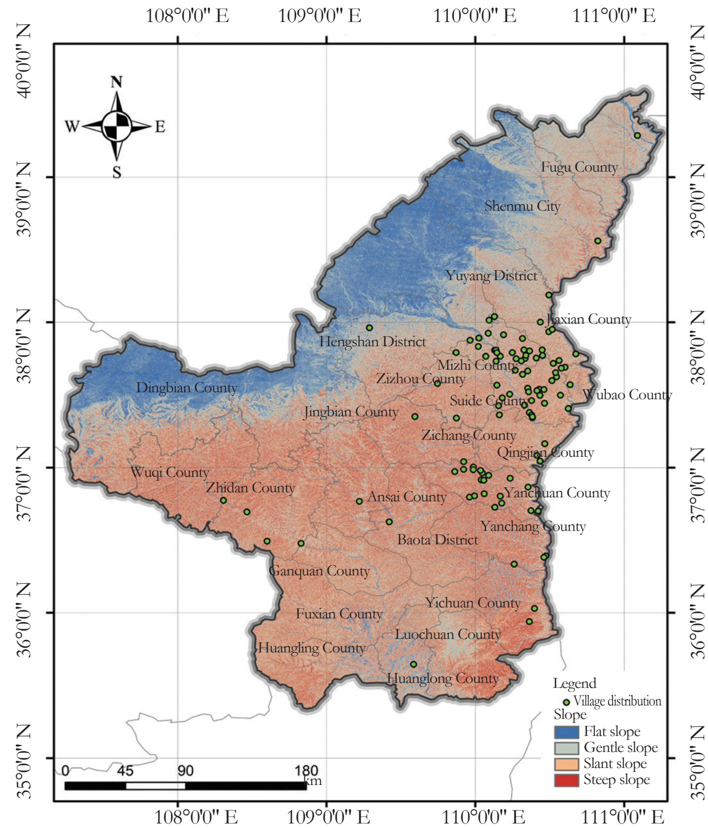


Fig.2 Distribution slope of cave dwelling villages in northern Shaanxi Province

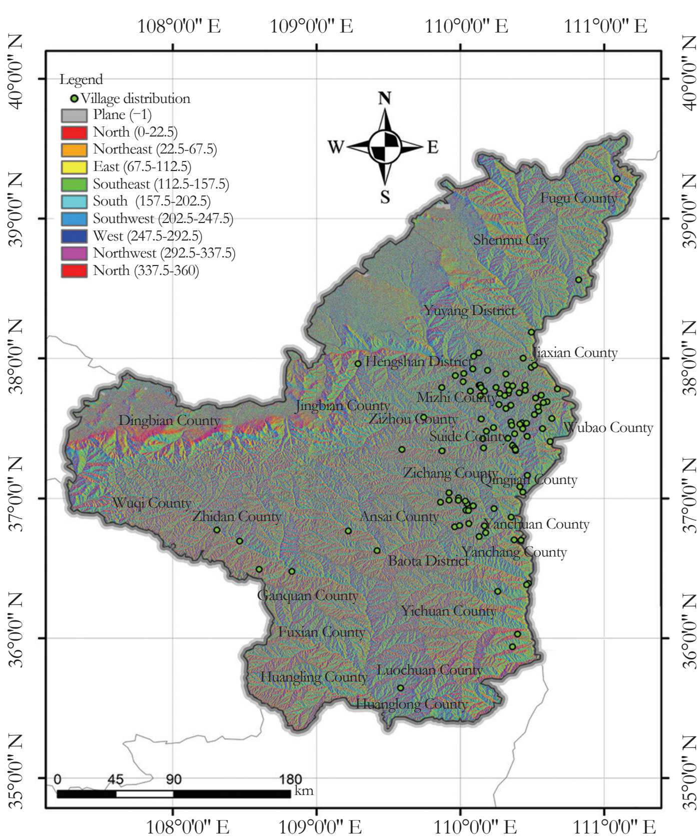


Fig.3 Distribution aspect of cave dwelling villages in northern Shaanxi Province

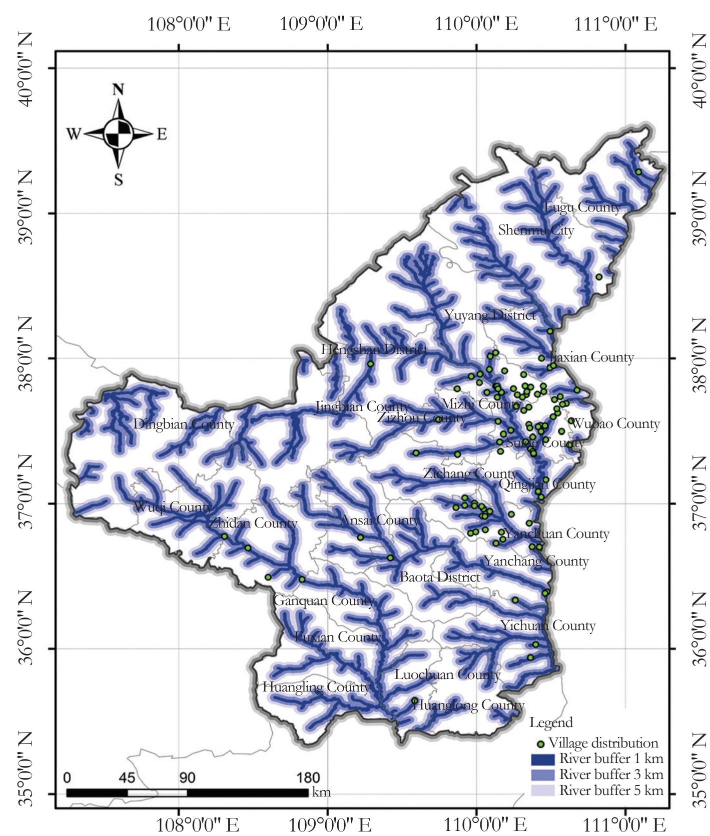


Fig.4 River buffers of cave dwelling villages in northern Shaanxi Province

are river valley, semi-slope platform, and beam-top slope[2]. A summary of the morphological features reveals that the majority of traditional cave dwelling villages in northern Shaanxi are constrained by the local climate and landscape elements, situated parallel to the contour line and developed to the east and west sides. The building layout is compact, with a D/H (distance/height) ratio of 2–5, distributed in a linear fashion (Table 3).

1.2.2 Climate adaptability principle. The configuration of a village's layout influences its access to solar radiation, which, in turn, affects the spatial thermal environment. The traditional cave dwelling villages of northern Shaanxi are constrained by the natural environmental elements of the north and south—namely, mountains and water—and have developed in a manner that allows for optimal solar radiation access. This is due to the orientation of the villages, which are situated in the south and face north.

Secondly, the shadows of buildings on sloping land are shorter than on flat land. Under the same solar elevation angle, the front and back layout of building groups can be more compact. This is exemplified by traditional cave dwelling villages in northern Shaanxi, which exhibit a morphology of successive construction and stacking of layers[3].

In light of the definition of shape coefficient ($f=F/V$) and the concept of shape factor ($k=l^2/s$) introduced in related studies[4], it can be ascertained that:

$$f=\frac{F}{V}=\frac{nhL+S}{nhS}=\frac{L}{S}+\frac{1}{nh}=\sqrt{\frac{k}{S}}+\frac{1}{nh}$$
$$=\sqrt{\frac{nhk}{V}}+\frac{1}{nh}$$

where f denotes the shape coefficient; F represents the exterior area of the building; V stands for the volume enclosed by the building; L is the perimeter of the bottom plane of the building; S denotes the area of the bottom surface of the building; n represents the number of building storeys; h represents the storey height of the building; and k stands for the building form factor.

It can be concluded that, under the condition that the shape of the building plane (k) is clear, when the number of building storeys (n) and the storey height of the building (h) are determined—that is to say, when the total height of the building is taken to be a fixed value—the shape coefficient (f) is inversely proportional to the volume (V). Thus, the larger the volume is, the smaller the value of the shape coefficient f is. Accordingly, the configuration of blocks utilized in the construction of the building group can serve to diminish the overall shape coefficient. Reducing the channel of heat exchange with the external environment is highly beneficial for the building's winter heat loss in northern Shaanxi, where the winter climate is extremely cold and distinctive.

The configuration of traditional cave dwellings in northern Shaanxi Province allows for optimal airflow during the summer months and effectively mitigates the impact of cold winds during the winter. The orientation of the building layout is frequently aligned at an angle to the prevailing wind direction during the summer months. This increases the angle of incidence of the summer wind, expands the ventilation spacing, and subsequently reduces the area of the wind shadow zone. The cross-staggered, free, and flexible layout allows for the reduction of wind resistance between the buildings.

In comparison to ventilation, the prevention of wind in winter is a relatively straightforward process. The cave dwellings in northern Shaanxi are arranged on the south-facing hillside, resulting in a gradual change of building height and volume from south to north. Such a combination is conducive to blocking the cold wind in the north and absorbing solar radiation during the winter months.

2 Principles of climate adaptability at the level of spatial organization

2.1 Street organization

2.1.1 Characteristics of street organization. The configuration of streets represents the fundamental spatial structure of traditional villages. The configuration of streets in traditional cave dwellings is markedly influenced by the surrounding natural environment. The distinctive features of these settlements reflect a clear interdependence between the village and the topography and climatic conditions. They also demonstrate the ways in which local residents have adapted and transformed their settlements in response to the natural environment.

In accordance with the aforementioned division of village layout patterns, a summary of the characteristics of the street organization of traditional cave dwelling villages in northern Shaanxi Province reveals that the street layout of these villages can be divided into two main categories: streets parallel to the contour line (Table 4) and roadways perpendicular to the contour line[5]. From a functional standpoint, the streets serve as the primary means of east-west connectivity, forming the nucleus of the village's transportation infrastructure. The area is spacious and conducive to leisure activities, offering a suitable environment for residents to reside in for extended periods. The roadway is a secondary arterial road that connects various building groups and streets in a north-south direction. The limited gradient and shading of the buildings on both the east and west sides result in a strong sense of spatial enclosure along the road, with a prevailing sense of slow

Table 1 Solar elevation angle in partial areas of northern Shaanxi Province

Geographical name	East longitude	Northern latitude	Solar elevation angle		
			Summer solstice	Equinoxes	Winter solstice
Fugu	111°04'	39°03'	74°23'	50°57'	27°31'
Mizhi	110°14'	37°47'	75°39'	52°13'	28°47'
Jiaxian	110°29'	38°02'	75°24'	51°59'	28°32'
Suide	110°14'	37°29'	75°57'	52°31'	29°05'
Zizhou	110°03'	37°27'	75°59'	52°33'	29°07'
Yan'an	109°28'	36°36'	76°40'	53°24'	29°58'
Xi'an	108°57'	34°16'	79°10'	55°44'	32°18'

Table 2 Building arrangement in different wind direction zones

Partition	Name of wind direction zone	Air flow characteristics	Building arrangement
1	Windward slope area	Wind direction perpendicular to the contour line	Buildings should be placed parallel or diagonally across the contour lines
2	Downwind slope area	Air flow along the contour line	Buildings should be placed diagonally across the contour lines
3	Leeward slope area	Potential generation of reeling wind or eddy wind	Buildings that do not require ventilation can be arranged in this area
4	Eddy wind area	Generation of eddy wind in the horizontal plane	Buildings that do not require ventilation can be arranged in this area
5	High-pressure wind area	Areas with high wind pressure	Tall buildings should not be built to avoid larger eddy wind in the leeward eddy wind area
6	Over hill wind area	Wind passed over the top of the mountain	There are notable occurrence of cool breezes in summer and it is prudent to consider the provision of wind protection in winter

movement through the space. With regard to the spatial scale, streets are observed to be wider, with a width of approximately 5–7 m and a D/H ratio of about 1.0–2.5. In contrast, roadways are found to be smaller, with a width of about 2.6–5.0 m and a D/H ratio of approximately 0.7–2.0. Furthermore, the traditional cave dwelling villages also feature pathways in front of each residence, which are not included in this study as they do not adhere to the typical form.

2.1.2 Climate adaptability principle. An appropriate street scale is conducive to maintaining a balanced temperature within the building complex. Due to the large width of the east-west street, in conjunction with the solar elevation angle affecting solar radiation previously mentioned, it can be seen that under identical sunlight conditions, the wider the width, the larger the heated area, the more dispersed the light, and the less the intensity of solar radiation per unit gained[6]. This is the reason why people prefer to stay in this area (Fig.8). In contrast, the open scale of the street allows for optimal access to daylight during the winter months, thereby ensuring favorable outdoor thermal conditions throughout the year. The general scale of the roadway is relatively modest, while the terrain height difference is considerable. Due to the elevated altitude angle, the sunlight forms a shaded area in the roadway during the summer months, creating a certain shading effect that benefits the passive cooling of the cave dwelling village.

The configuration and dimensions of the streets have a direct impact on the wind environment within the village. During the summer months, roadways that are perpendicular to the contour line are shielded from direct sunlight. Concurrently, roadways oriented in a north-south direction serve as vents oriented in the direction of the predominant summer winds. This integration of the summer southerly winds into the building mass results in a notable reduction in the air temperature within the roadways compared to the external temperature. The east-west opening of the cave dwelling structure allows for the discharge of hot air within the room, creating a thermal pressure differential with the cold air in the roadway. This accelerates the loss of hot air by utilizing the hot pressure effect.

Table 3 Morphological characteristics of the layout of cave dwelling villages in northern Shaanxi Province

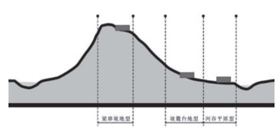
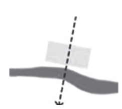
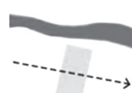
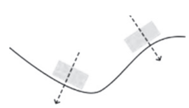
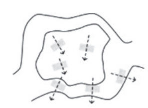
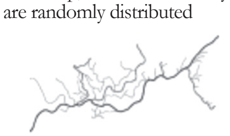
Characteristic analysis	Layout pattern type			
	River valley		Semi-slope platform	Beam-top slope
Location distribution	River valley		Semi-slope	Top of slope
Profile				
Orientation feature	North of the river Vertical river	South of the river Parallel river	Perpendicular to the contour line	Diverse orientations
				
Cave combination method	Compact type	Semi-compact type		Dispersive type
Plane shape	Linear	Linear		Irregular clusters
D/H	2–5	>3		≤ 3
				
Group layout characteristics	Parallel to the river with a regular form		Parallel to the contour line	Randomized layout
				

Table 4 Characteristics of street organization of traditional cave dwelling villages in northern Shaanxi Province

Characteristics of street organization	Layout pattern type		
	River valley	Semi-slope platform	Beam-top slope
Influence factor	River valley	Mountain	Mountain
Restricted condition	Towards the direction of the rivers	Towards the direction of the contour lines	Towards the direction of the beam top
Street layout	Streets parallel to the rivers, roadways perpendicular to the rivers	Streets parallel to the contour lines, roadways perpendicular to the contour lines	The configuration of the streets is aligned with the beam top, while the roadways are randomly distributed
			
Street dimension	Street D/H≈1.0–1.5	Street D/H≈1.1–2.1	Street D/H≈1.5–2.5
	Roadway D/H≈0.7–1.0	Roadway D/H≈0.8–1.5	Roadway D/H≈1.1–2.0

2.2 Courtyard organization

2.2.1 Characteristics of courtyard organization. In traditional Chinese architecture, a courtyard is an open space enclosed by houses and walls or fences. However, in the loess gully region of northern Shaanxi, this concept is disrupted by the unique topography, which results in courtyards in such villages being enclosed by cave dwellings on only one or two sides, with no solid enclosure on the other three or two sides. The formation of this state is related to the topographic characteristics of the mountain itself, which creates an enclosing interface on the side facing the mountain, with no objects enclosing the remaining two to three sides. The spatial organization of traditional cave dwelling villages in northern Shaanxi can be classified according to the configuration of the surrounding environment, which can be broadly categorized as either "mountain-courtyard-courtyard" or "mountain-courtyard-mountain"[7] (Table 5). This typology primarily manifests in villages situated on the semi-slope platform and beam-top slope types.

2.2.2 Climate adaptability principle. As a buffer space for the exchange of indoor and outdoor climate, the cave dwelling villages in northern Shaanxi Province can effectively prevent the influence of overheated or overcooled air on the indoor and outdoor climatic environments, thereby ensuring the thermal stability of the indoor and outdoor spaces. The traditional cave dwelling courtyard villages in northern Shaanxi are typically connected to the streets. Due to the morphological scale differences between the street space and the courtyard space, the two spaces receive different solar radiation under the

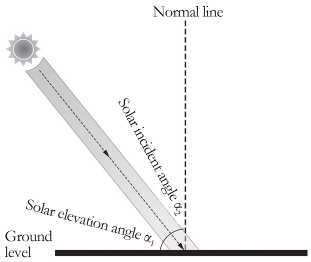


Fig.5 Solar elevation angle and solar incident angle

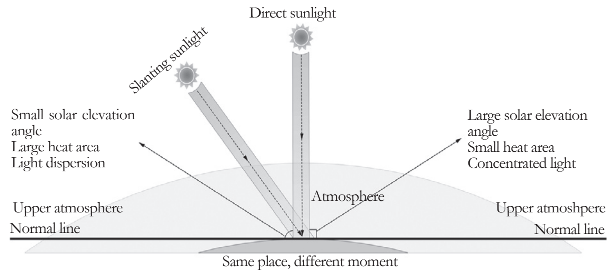


Fig.6 Plot of solar incidence angle versus solar radiation

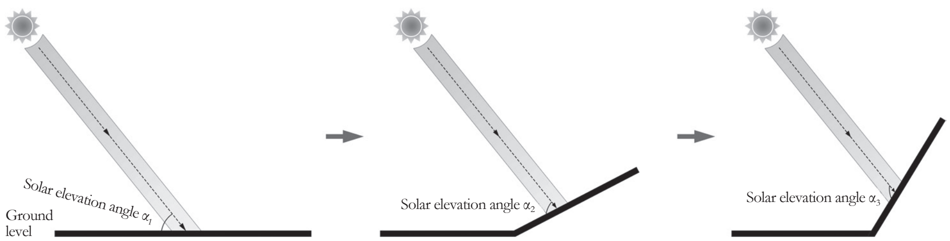


Fig.7 Effect of sloping land on solar elevation angle

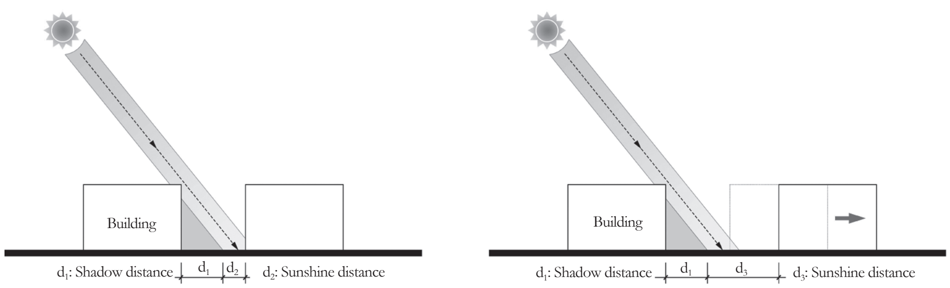


Fig.8 Comparison of solar radiation intensity at different widths

same conditions, and the air temperature is also disparate, thereby forming a pressure difference convection exchange that serves to regulate the air temperature within the courtyard. The height of the courtyard walls in traditional cave dwelling villages in northern Shaanxi is 1.0-1.6 m, which allows for the introduction of roadway winds into the courtyard during the summer months. Furthermore, the plan dimension of the courtyard affects the distribution of the wind field. The D/H ratio of the courtyard in traditional cave dwelling villages in northern Shaanxi Province is predominantly within the range of 0.8–1.5. The wind field distribution in the courtyard is more uniform, thus the layout of the courtyard creates an optimal outdoor environment. Additionally, the courtyard space of the cave dwelling buildings in northern Shaanxi Province accommodates a multitude of the inhabitants' living activities.

3 Urban space form design strategies

In light of the climatic conditions prevalent in northern Shaanxi, it is imperative that the planning of settlements and the design of urban space patterns take into account the climatic environment requirements of "heat gain and wind protection in winter, heat dissipation and ventilation in summer". This should be done as early as possible in the design process in order to achieve good climatic adaptability through the implementation of climate-adaptive design strategies, the creation of optimal indoor and outdoor spaces, and a reduction in the reliance on active equipment such as air conditioners.

The preceding paper provided an overview of the characteristics of traditional cave-dwelling villages in northern Shaanxi, focusing on the site layout and spatial organization. It also examined the principles of climate adaptability, which are now condensed to summarize the urban spatial form design strategy based on the climate adaptability principles of regional architecture.

3.1 Heat gain and wind protection strategy in winter

3.1.1 Taking advantage of terrain elevation differences to gain sufficient sunlight. As demonstrated in the preceding analysis, in the northern region of Shaanxi Province, where the solar elevation angle is relatively low, the solar elevation angle can be augmented by selecting a site on a sloping land. This approach enables a more concentrated distribution of light, thereby facilitating the capture of a greater amount of solar radiation. In the design of urban space forms, the treatment of sloping land should not be limited to mere excavation; rather, they should be rationally utilized to obtain more solar radiation in winter and reduce the reliance on energy-consuming equipment.

3.1.2 Optimizing the shape of clusters to reduce building energy consumption. In the context of urban spatial form design, it is essential to exercise control over the shape coefficient of the building or building group to minimize superfluous embellishments. By reducing the external surface area exposed to the external environment per unit volume, it is possible to limit the "channel" of heat exchange between the building and the surrounding climate. This approach offers significant advantages in terms of reducing heat gain during the summer and heat loss during the winter, thereby reducing the energy consumption of the building.

3.1.3 Taking into account the winter and summer seasons to select the optimal orientation of the building. In the design of urban space forms, the orientation of the group should be at an angle with the dominant summer wind, increasing the angle of incidence, increasing the ventilation spacing, and avoiding the generation of wind shadow zones. Concurrently, a reasonable orientation of the group can facilitate greater sunlight angle and enhance heat radiation in winter, thereby improving the thermal environment.

3.1.4 Combining height and length to create natural masking. In accordance with the prevailing wind direction characteristic of the local climate, the height and length of the building are rationally arranged in relation to one another. In order to consider the effects of summer ventilation and winter wind protection, it is advisable to situate taller, more expansive buildings in the northernmost area of the construction site, while positioning smaller, less imposing structures in the southern region. This arrangement creates a pattern of higher structures in the north and lower structures in the south, which is conducive to the obstruction of cold winds in the northern area and facilitates the absorption of solar radiation during winter months. Furthermore, the installation of "climate protection units", which may take the form of walls, panels, or greenery, can serve to mitigate the effects of cold air.

3.2 Heat dissipation and ventilation strategy in summer

3.2.1 Controlling D/H ratio to promote a

Table 5 Characteristics of courtyard organization of traditional cave dwelling villages in northern Shaanxi Province

Characteristics of courtyard organization	Layout pattern type					
	River valley		Semi-slope platform		Beam-top slope	
Courtyard type	Street–Courtyard–Street		Mountain–Courtyard–Courtyard Mountain–Courtyard–Street Mountain–Courtyard–Mountain		Mountain–Courtyard–Street Mountain–Courtyard–Mountain	
Courtyard enclosure interface	Cave dwelling + courtyard wall		Cave dwelling + guardrail/ courtyard wall		Cave dwelling + guardrail/courtyard wall	
Spatial scale	Length (m)	15–28	Length (m)	14–30	Length (m)	10–40
	Width (m)	12–30	Width (m)	8–16	Width (m)	8–15

balance of heat gain and cooling of the group. In urban design, streets of varying directions should be strategically planned to accommodate climatic conditions through the incorporation of diverse widths and functions. For instance, the east-west streets should be of a sufficient width to accommodate the primary traffic flow and provide adequate sunlight for building. Conversely, the north-south roadway should be narrower to allow for passive cooling. By regulating the D/H ratio of the roadway, the solar heat gain from the floor to the wall can be mitigated. The solar elevation angle attains its maximum value over the course of the year at noon on the summer solstice in northern Shaanxi. As illustrated in the figure, the solar elevation angle at the summer solstice in northern Shaanxi is approximately 75°. This can be expressed as tan75°=3.732, which indicates that when the D/H ratio of the roadway is approximately 3.7–4.1, the roadway floor is exposed to sunlight for a minimal amount of time, thereby maintaining a cool environment. In the particular design, the optimal width of the roadway can be determined based on the specific building height.

3.2.2 Setting vents properly to optimize group ventilation. It is inadvisable to construct townhouses of excessive length in a direction that is subject to the prevailing summer winds. In order to facilitate the incorporation of summer southerly winds into the building mass, vents should be provided at appropriate locations. Furthermore, the design of an effective wind guide path is of great importance in promoting natural ventilation within urban areas. The direction of the wind lane should align with the dominant wind direction during the summer months or perpendicular to the surrounding river system. It is optimal for the lane to be continuous, smooth, and for both sides of the interface to be leveled to facilitate wind guidance, thereby allowing the wind to penetrate deeply into the interior of the urban space.

3.2.3 Setting climate buffers to increase the level of climate response. The incorporation of transition spaces within the thermal environment, which may be conceptualized as climatic buffers, can facilitate the establishment of a dynamic interface between the built environment and the external climate, contingent upon the specific functional requirements of the building in question. The smaller temperature differential between the climate buffer and the external climate than that between the indoor space and the external climate results in a reduction in heat loss from the external surface, thereby enhancing the thermal stability of the main space. The south-facing climate buffer can be utilized for heat collection and storage, thereby providing heat to adjacent spaces.

In traditional cave dwelling villages, the climate buffer is primarily manifested in courtyards. In contemporary urban spatial pattern design, courtyards, gray spaces, foyers, and interdome can be incorporated to enhance indoor and outdoor thermal stability.

4 Conclusions

Through analysis, it can be observed that traditional cave dwelling villages in northern Shaanxi are predominantly situated on south-facing slopes in proximity to water at low altitudes. These villages are characterized by compact building groups and east-west development, which is constrained by the elements of mountains and rivers. A two-level street system is generated, comprising streets parallel to the contour line and roadways perpendicular to the contour line. This results in the formation of a courtyard form enclosed by mountains. Such site layout and spatial organization exhibit excellent climate adaptability with regard to heat, ventilation, and wind storage. In light of the aforementioned considerations, the following urban spatial form design strategies are put forth: ① the topographic height difference can be exploited to obtain sufficient sunshine; ② the group shape can be optimized in order to reduce building energy consumption; ③ the best orientation of the building can be chosen to take account of both winter and summer conditions; ④ the height and length can be combined in order to form natural masking; ⑤ the D/H ratio of streets and roadways should be controlled to achieve a balance between heat gain and cooling of groups; ⑥ vents should be set appropriately to optimize group ventilation; ⑦ climate buffers should be established to increase the level of climate response. This paper examines the principle of climate adaptability in regional architecture, which serves to safeguard regional architectural heritage. It applies the principles of eco-design to current settlement planning and urban space pattern design, thereby positively impacting the reduction of building energy consumption, the reduction of carbon emissions throughout the building's life cycle, and the creation of a superior living environment.

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