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Study on the Correlation Between the Preservation Status of Mountain Ancient Buildings, Wind Environment, and Protection Methods — A Case Study of the Rock Temples on Wudang Mountain

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Abstract: The preservation condition of historical buildings is closely related to their ventilation environment. This study focuses on the rock temples in Wudang Mountain, specifically comparing the ventilation conditions of Yinxian Rock and Huayang Rock. The following conclusions are drawn: (1) The main wind direction at Yinxian Rock aligns with its orientation, which is an easterly wind, while Huayang Rock experiences a westerly wind, deviating from its southwestern entrance; (2) Huayang Rock has significantly lower wind speeds compared to Yinxian Rock, with minimal airflow; (3) The surrounding environment of Huayang Rock features steep terrain, dense tree cover, and the presence of railings and other structures that impede wind entry into the cave, whereas Yinxian Rock is surrounded by fewer trees and has a flat terrain; (4) In terms of cave morphology, Yinxian Rock is completely open on the east side, while Huayang Rock's opening accounts for only half of its area and is not directly aligned with the rock temple. In summary, Huayang Rock's ventilation environment is inferior to that of Yinxian Rock, leading to more severe pathologies. It is inferred that Huayang Rock's preservation issues are closely related to its poor ventilation environment. Therefore, improving its ventilation conditions is crucial for preventive conservation. Using environmental simulation, this study compares the ventilation conditions of Huayang Rock under different wind directions and speeds, identifies the two most ideal scenarios, and proposes several feasible solutions.

Keywords: Wudang Mountain rock temple; Architectural issues; Natural ventilation; Preventive conservation

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1. Introduction

Wudang Mountain, a famous Taoist holy site in China, is located in Danjiangkou City, Hubei Province. The mountain is home to a large number of brick and stone buildings, representing the most traditional and concentrated brick and stone surface building groups in China. Currently, there are more than twenty rock temples with their main structures still preserved, most of which face challenges in access and maintenance for protection and management. Continuous environmental impacts have had a negative effect on them, causing various degrees of damage that are becoming more severe. Due to the scarcity of relevant literature on Wudang Mountain's rock temples and the inadequacy of analysis on their brick and stone buildings, there is a lack of specific interpretation of the causes of their architectural issues and research on protective measures [1]. This has led to a delay in timely protection and accelerated the severity of their architectural issues. Currently, domestic researchers such as Wang Zi have explored the mechanism of "water" on the architectural issues of Wudang Mountain's brick and stone buildings, and Wang Chengnan *et al.* have further analyzed that the main cause of the peeling phenomenon in Wudang Mountain's rock temples is the water-rock interaction [2,3]. However, other environmental factors affecting the architectural issues have not been fully explored, and there is almost no research on the correlation between the architectural issues of Wudang Mountain's rock temples and the wind environment. Regarding natural ventilation of stone cultural relics, Wang Jiangli *et al.* have explored the airflow movement patterns and ventilation control methods in Mogao Caves through a series of natural ventilation tests and Zhou Baofa *et al.* have also analyzed the influencing factors and control measures of natural ventilation in Maijishan Grottoes [4–8]. However, due to the unique characteristics and environmental conditions of Wudang Mountain, its natural ventilation differs from these cases.

Yinxian Rock and Huayang Rock are two rock temples on Wudang Mountain that have high research and protection value. Yinxian Rock is located north of the Five Dragon Palace, in Lujiazhai Village, under Yinxian Peak. Many accomplished Taoist practitioners, such as the famous alchemists Yin Xi and Yin Gui, once lived and practiced here in secrecy, giving Yinxian Rock its long-standing reputation. The rock cave faces east, and there are five brick and stone halls inside, forming a "pin" shaped layout centered around the main hall, as shown in **Figure 1**. Huayang Rock, also one of the thirty-six rocks of Wudang Mountain, is located more than 200 m away from the Five Dragon Palace, facing southwest opposite to Yunmu Rock. Surrounded by trees, there is only one stone hall inside the rock, as shown in **Figure 2**. According to records, the construction of the stone halls in both rock temples dates back to the Ming Dynasty [9]. Under the same climatic conditions, the altitude of the two rocks is also similar, with Yinxian Rock at 604.5 m and Huayang Rock at 647.8 m. Both use a mixture of brick and stone as building materials, and their architectural features and construction techniques are basically the same [10]. However, there is a significant difference in their degree of damage.

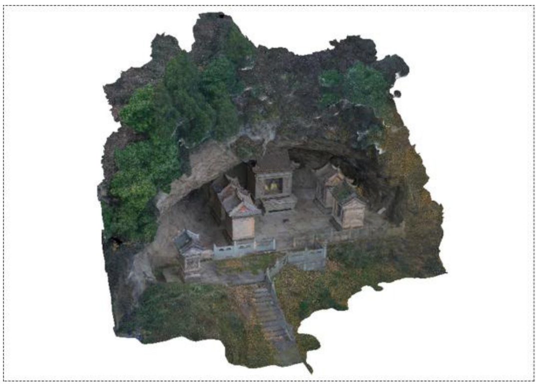


Figure 1. Yinxian Rock

Figure 2. Huayang Rock

The preservation status of cultural relic buildings is closely related to the micro-environmental conditions in which they are located [11]. For stone cultural relics in damp areas, the ventilation environment is an important indicator that affects the surface deterioration [12]. As the wind speed increases, the heat exchange on the building surface also increases, with the convective heat exchange on the windward side being greater than that on the leeward side, leading to an increase in the surface temperature of the building and stronger evaporation of water from the bricks and stones [13]. A good ventilation environment can remove moisture from the building surface, reducing some architectural issues caused by water.

In the Wudang Mountain area, where the east wind is the predominant wind direction, Yinxian Rock and Huayang Rock face almost opposite directions, so their wind exposure conditions will also be different. To further explore the relationship between the ventilation environment of the two rocks and the difference in the degree of architectural issues they suffer, this paper compares the ventilation conditions of Yinxian Rock and Huayang Rock in terms of wind direction, wind speed outside the cave, the surrounding environment of the building, and the shape of the cave. The analysis reveals that the ventilation environment of Huayang Rock is relatively poor compared to Yinxian Rock. Through real-time environmental monitoring and data analysis of the wind direction and speed in front of the two caves, it is found that the main wind direction at Yinxian Rock is easterly, while at Huayang Rock it is westerly, and the monitored wind speed at Huayang Rock is much lower than that at Yinxian Rock.

Theoretical analysis of the cave shape and surrounding environment shows that the terrain around Yinxian Rock is flat with few trees, while the opposite is true for Huayang Rock. The east side of Yinxian Rock is completely open, favoring wind exposure, while the opening area of Huayang Rock is only about half of its facing side. To find an ideal ventilation effect for Huayang Rock and improve its current ventilation status, this paper roughly simulates the ventilation situation of Huayang Rock under different wind directions and speeds through environmental simulation. It is found that the better ventilation effect for Huayang Rock occurs with a south or southwest wind, with wind speeds of around 5 m/s and 10 m/s, respectively. Based on this, several implementable operations are proposed, providing a scientific basis and theoretical foundation for the preventive protection of Huayang Rock in the future.

2. Comparison of architectural issue conditions and ventilation environments between Yinxian Rock and Huayang Rock

Comparing the architectural issue conditions of Yinxian Rock and Huayang Rock, significant differences in the degree of architectural issue were observed at the same height of approximately 90 cm on the Xumizuo (a type of stone pedestal in traditional Chinese architecture). The west side of the Xumizuo in Huayang Rock Temple showed large areas of powdery peeling, while the east side exhibited considerable erosion and defects. The south side had a relatively minor degree of architectural issue, but there were still some signs of powdery peeling and erosion [14]. On the other hand, when examining the main hall's altar table and the northeast and southwest side halls of Yinxian Rock, and comparing the same Xumizuo areas, it was found that there was almost no peeling, only a small amount of weathering erosion [10]. From this, it can be roughly inferred that the degree of architectural issue suffered by Yinxian Rock is less severe than that of Huayang Rock.

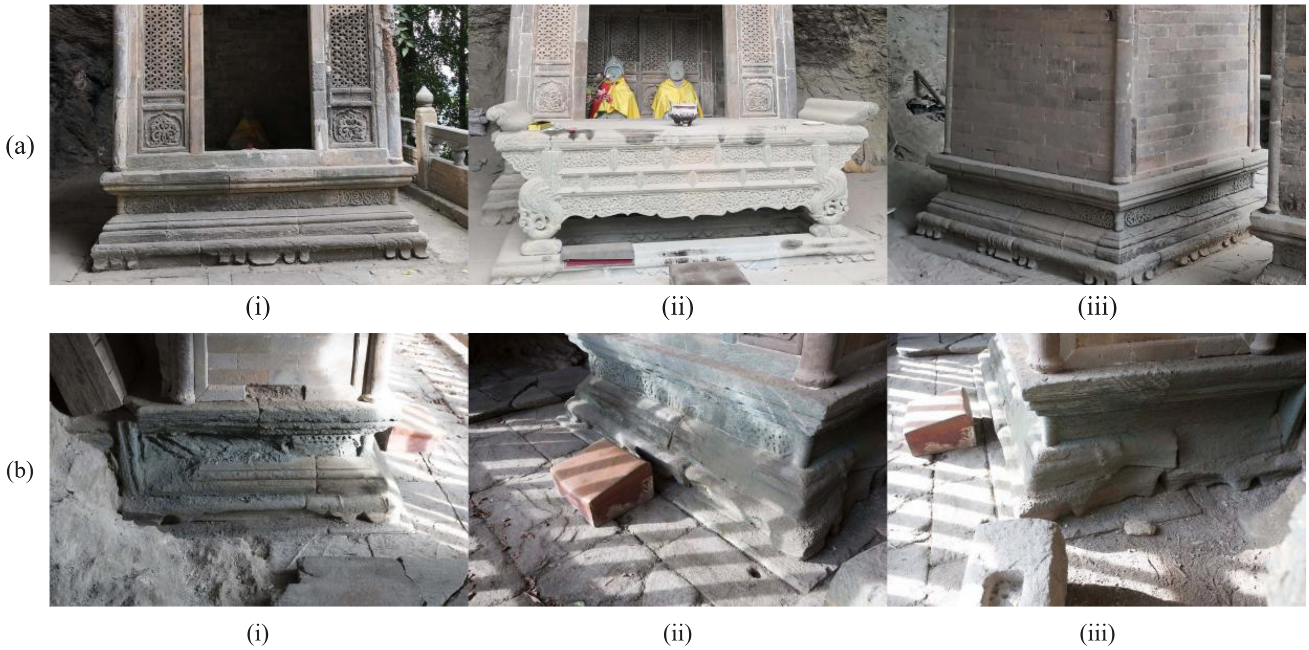


Figure 3. Photographs of architectural issues on the two rocks (a) Yinxian Rock (b) Huayang Rock

The surface integrity damage suffered by the Xumizuo of Huayang Rock can be roughly divided into six types: defects, powdery peeling, layered peeling, massive peeling, erosion, and hole-like weathering, as shown in **Figure 3(b)**. Among them, peeling is the most significant architectural issue that causes the greatest degree of damage to the rock temple. Its mechanism is mainly due to water-rock interaction, which primarily involves the hydration and expansion of clay minerals and the dissolution of soluble minerals in the rock temple's stone material [3]. The widespread presence of moisture accelerates the formation of peeling architectural issues in the rock temple, and the wind environment is one of the important factors that affect the amount of water residue on the building surface.

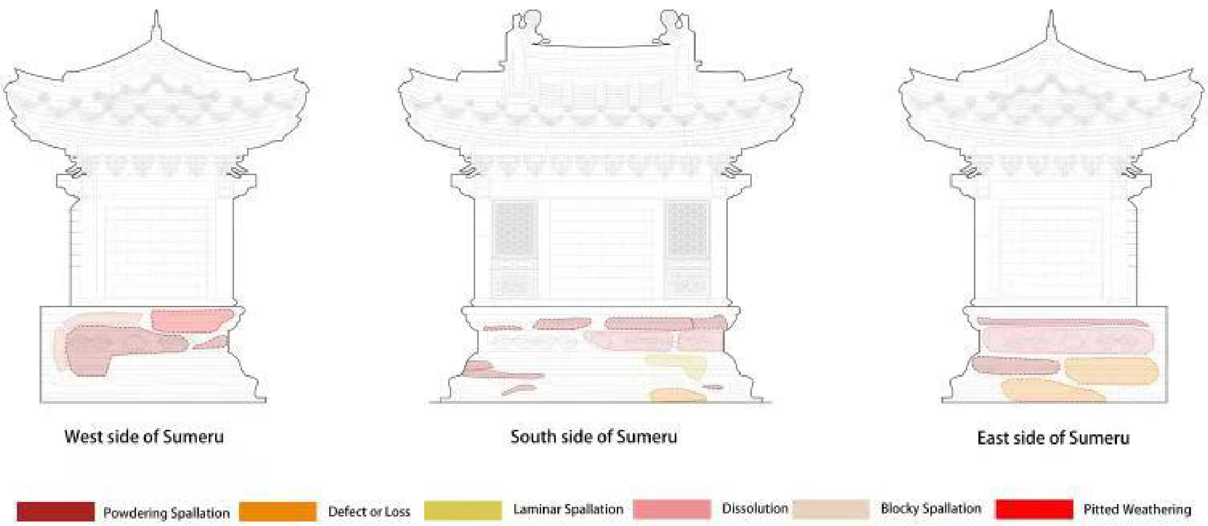


Figure 4. Cloud map of main architectural issues on the Xumizuo of Huayang Rock

To explore the correlation between the differences in architectural issues of the two rocks and their ventilation environments, it is necessary to understand the external ventilation conditions of the buildings and the reasons that affect their ventilation. It is known that natural ventilation is divided into three modes: wind pressure ventilation, thermal pressure ventilation, and combined wind and thermal pressure ventilation [15]. Wind pressure ventilation is related to the indoor and outdoor wind speeds. When the internal wind speed is constant, the greater the outdoor wind speed, the larger the wind pressure difference formed, and the better the ventilation effect. Thermal pressure ventilation is caused by air flow due to differences in air density resulting from temperature differences between indoor and outdoor air and height differences between inlet and outlet. To increase thermal pressure ventilation, while utilizing the temperature difference between indoor and outdoor air, it is necessary to create upper and lower openings to allow airflow to enter from the bottom and exit from the top.

The ventilation situation of rock temples can be analogized to the principle of architectural ventilation, treating the caves as buildings with a single-side opening. The wind exposure outside the rock temple buildings can be considered as the ventilation conditions inside the caves, and the outdoor wind speed can be regarded as the wind speed inside the caves [16]. Since there is no height difference between the inlet and outlet of the single-side opening of the rock temples, the natural ventilation mode of the two rock temples is basically wind pressure ventilation. The factors that affect wind pressure ventilation include external factors such as wind speed outside the cave and the surrounding environment, as well as internal factors such as the opening of the cave and its own shape. For rock temple buildings, the temperature changes inside the caves can be ignored, so it is only necessary to investigate the wind speed changes outside the caves. The following sections will compare the ventilation environments of Yinxian Rock and Huayang Rock in terms of wind direction and speed outside the caves, the surrounding environment of the caves, and the openings and shapes of the caves.

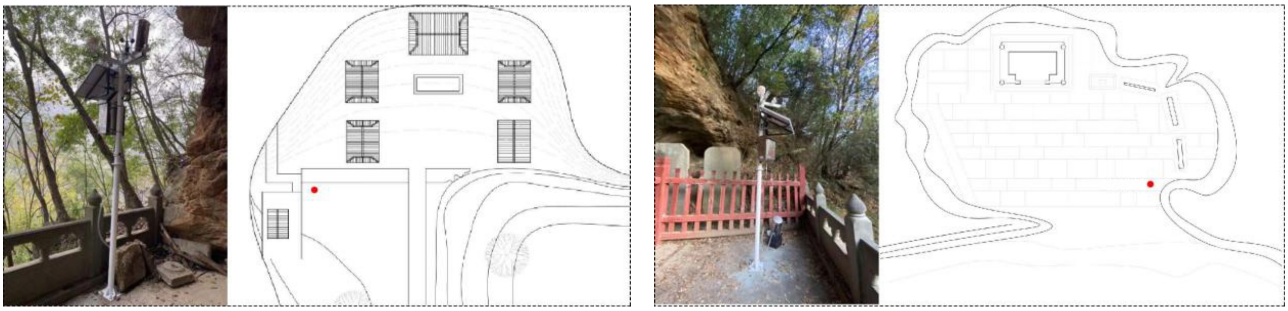
2.1. Wind direction and speed

Wind speed and direction are two fundamental characteristics of natural wind and the main factors influencing the ventilation environment. To measure the environmental data of the two rocks, we used outdoor weather station monitors to observe the changes in the surrounding environment of the two rocks and record data in real time. The models are shown in **Table 1** below. The test indicators include air temperature and humidity, gas concentration, illumination, ultraviolet (UV) intensity, as well as wind force, speed, and direction. Sampling was done at 10-minute intervals to capture instantaneous values. This article will focus on three indicators: wind force, speed, and direction.

Table 1. Monitor models and measurement ranges

Measurement variable	Instrument brand & model	Instrument accuracy	Sampling interval (min)
Wind direction	JianDaRenKe Weather Station &RS-QXZ	± 45°	10
Wind speed	JianDaRenKe Weather Station &RS-QXZ	± 0.1 m/s	10
Wind force	JianDaRenKe Weather Station &RS-QXZ	Level 1	10

Instruments were placed on the sides of the air intakes of two rock temples to detect their overall environmental conditions, as shown in **Figure 5(a)** and **Figure 5(b)**. Data collected over four months from November 2022 to February 2023 were analyzed. Due to signal issues, some data were missing. Therefore, days with complete data for both temples were selected as the sample size for this analysis, ensuring at least ten days of data per month. This data volume is sufficient and representative, allowing for the derivation of general patterns. The following analysis is based on this dataset.



(a) (b)

Figure 5. Locations of meteorological stations at (a) Yinxian Rock and (b) Huayang Rock

As a reference, this paper selects meteorological station data from Mount Wudang over the same four-month period, with indicators including dd (wind direction at 10–12 m above ground level within 10 min before observation, compass bearing), ff (average wind speed at 10–12 m above ground level within 10 min before observation, m/s), and ff3 (maximum gust wind speed at 10–12 m above ground level between two observations, m/s). These indicators were monitored every three hours, daily. The collected data were then compared with the monthly average and maximum wind speeds, overall wind force distribution, and wind direction distribution at Yinxian Rock and Huayang Rock.

As shown in **Figure 6(a)** and **Figure 6(b)**, the average and maximum wind speeds at both rock temples are significantly lower than those at the local area, with Yinxian Rock having noticeably higher wind speeds than Huayang Rock. The four-month overall average wind speed at Yinxian Rock is approximately 0.17 m/s, while that at Huayang Rock is about 0.01 m/s, and Mount Wudang records around 1.8 m/s. It is worth noting that Huayang Rock experienced an almost windless environment in November, with average monthly wind speeds remaining stable between 0.01 and 0.02 m/s over the four months. Both rocks showed a monthly increasing trend in wind speed from November to February. The monthly average maximum wind speed at Mount Wudang stabilized at around 5.25 m/s, whereas Yinxian Rock demonstrated a clear upward trend, ranging from 1.9 m/s to 3.6 m/s. In contrast, Huayang Rock recorded only 0.1 m/s in November, stabilizing at approximately 1.5 m/s for the following three months.

Figure 7 illustrates the wind force distribution at Mount Wudang and the two rocks. The wind force range at Mount Wudang spans from 0 to 5, with grades 1, 2, and 3 predominating and distributed relatively evenly, accounting for about 93%. Grades 0, 4, and 5 are less frequent. The wind force range at Yinxian Rock and Huayang Rock is limited to grades 0 to 3 (based on the "Wind Force Grade" national standard released in June 2012 in China, which divides wind force into 13 grades, with 0 being the minimum and 12 being the maximum). Yinxian Rock mostly experiences grades 0 and 1 winds, with few occurrences of grade 2 and only one day reaching grade 3. Huayang Rock, on the other hand, frequently encounters grade 0 winds, with limited days of grades 1 and 2 winds.

Figure 8 depicts the wind direction frequency. According to the figure, the prevailing winds at Mount Wudang are primarily eastern winds, with northeast and southeast winds being the most frequent. There are also some northwest and southwest winds, and among the cardinal directions, the east wind is the most prevalent, while other directions are less common, with the west wind significantly less frequent than the east. Yinxian Rock also exhibits a dominant east wind, followed by northeast and southeast winds, with a certain amount of north wind and fewer occurrences of other directions. In contrast, the main wind direction at Huayang Rock is west, with the west wind being the most frequent, followed by northwest and southwest winds, and all other directions are rare.

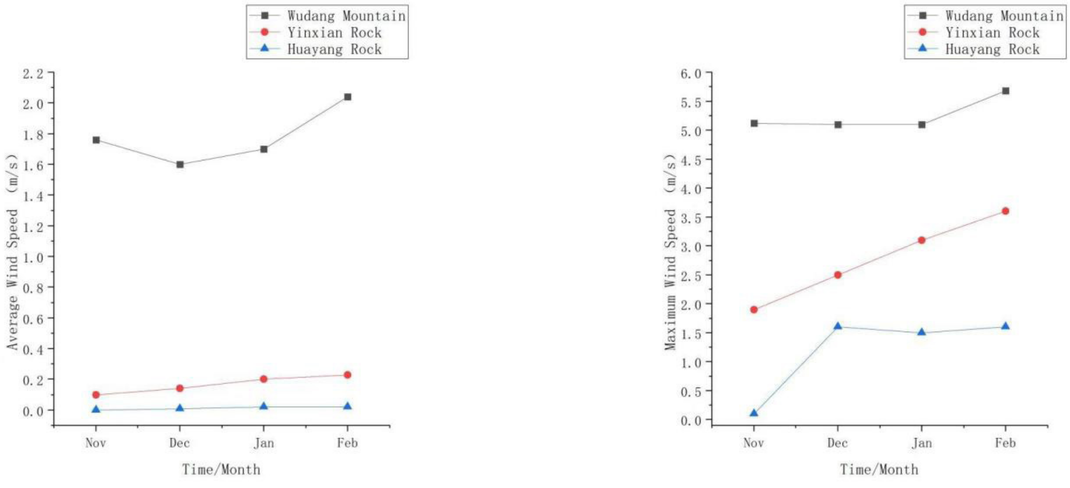


Figure 6. Comparison of wind speeds at Yinxian Rock, Huayang Rock, and Mount Wudang, (a) Average wind speed and (b) Maximum wind speed

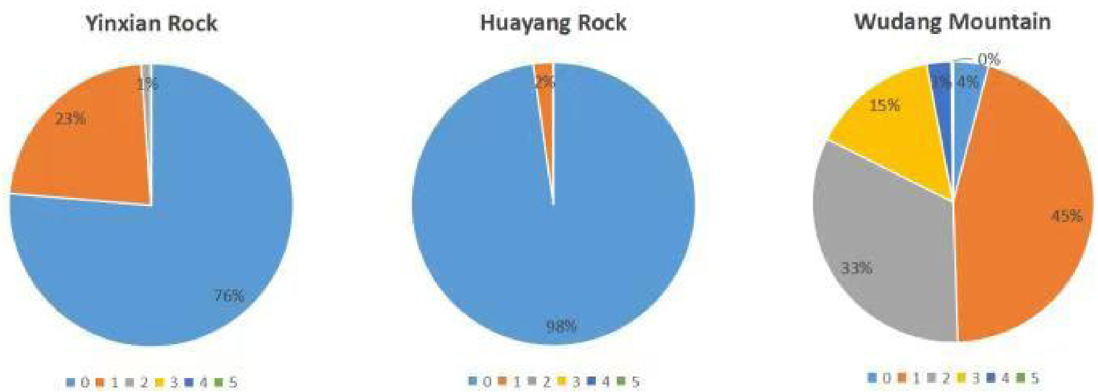


Figure 7. Statistical comparison of wind force at Yinxian Rock, Huayang Rock, and local area of Mount Wudang

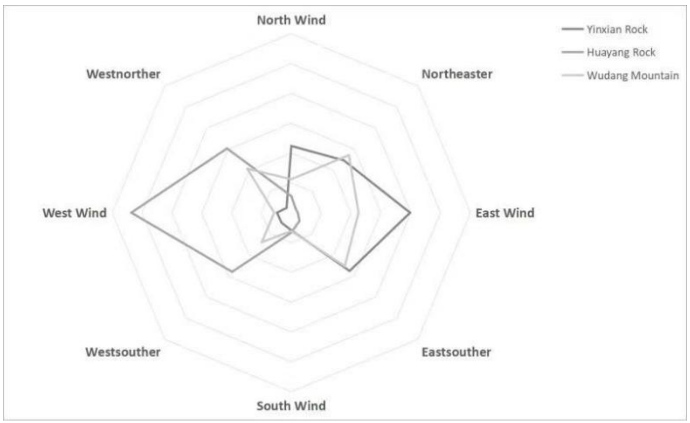


Figure 8. Comparison of wind direction frequency at Yinxian Rock, Huayang Rock, and local area of Mount Wudang

Based on the comparison charts above, it is evident that there are significant differences in the wind environments of Yinxian Rock and Huayang Rock. Both the average and maximum wind speeds at Huayang Rock are much lower than those at Yinxian Rock. The dominant wind directions also differ between the two rocks, with Yinxian Rock's primary wind direction aligning with the local prevailing wind, while Huayang

Rock exhibits the opposite trend. Simultaneously, the micro-environmental climates of Yinxian Rock and Huayang Rock deviate considerably from the local climate of Mount Wudang. This divergence is reflected in the much lower wind speeds at the entrances of the two rocks compared to the average wind speed in the local area of Mount Wudang, and the more uniform distribution of wind force.

2.2. Surrounding environment and cave formation

Factors contributing to the ventilation differences between the two rocks also include the surrounding environment, cave formation, and orientation of openings. Yinxian Rock is situated in a flat area with minimal obstruction from trees, and its ceiling is raised, allowing wind from various directions to flow into the cave. Additionally, Yinxian Rock's dimensions, including a height of 11.05 m, a width of 23.7 m, and a depth of 12.8 m, result in a total volume of approximately 1,676 m^3 (roughly half of a cube), making it a relatively large cave. The temple inside the cave maintains a certain distance from the cave walls, facilitating the formation of positive and negative pressure differences, as illustrated in **Figure 9(a)**.

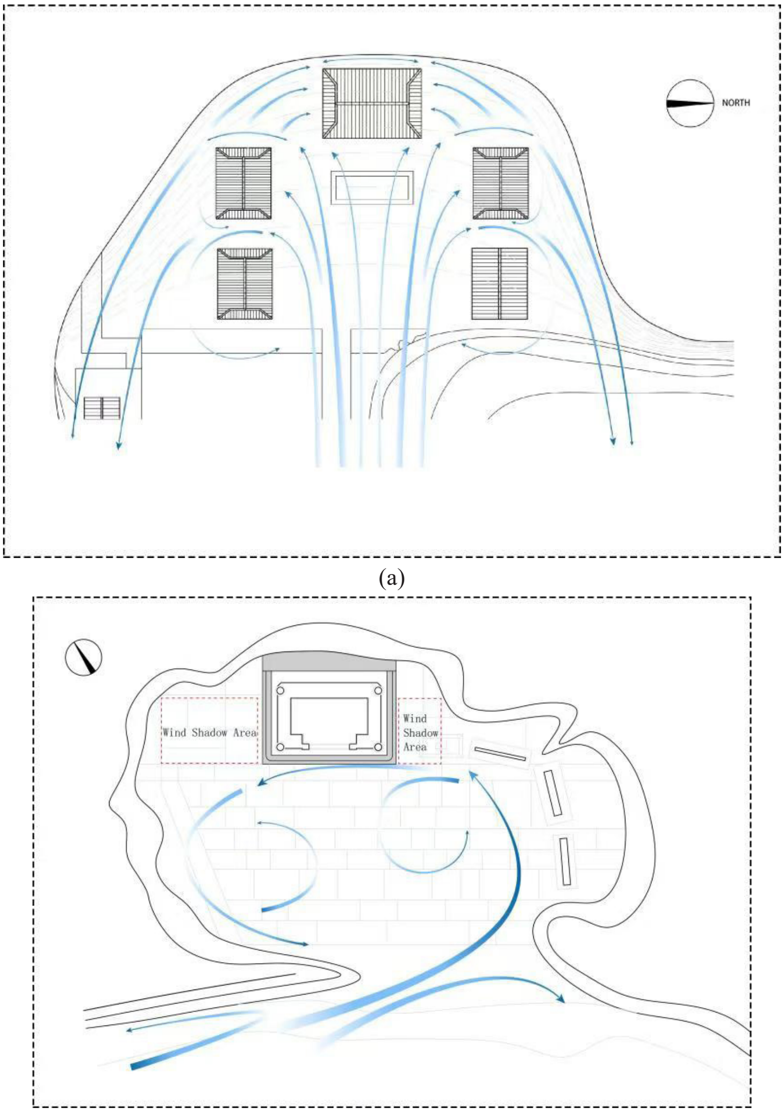
On the other hand, Huayang Rock is located on a slanted hillside surrounded by trees, with its entrance partially blocked by trees overhead. The addition of stone and wooden railings at the entrance also serves to block some external wind. Huayang Rock's dimensions, consisting of a height of 3.5 m, a width of 7.4 m, and a depth of 5.1 m, yield a total volume of approximately 132 m^3 (resembling a cube), indicating a smaller cavity, as shown in **Figure 9(b)**. Moreover, the back of the temple structure is tightly pressed against the cave wall, making it difficult for wind to pass through the narrow space and establish a stable airflow circulation. This aspect significantly impacts the ventilation conditions within Huayang Rock.

(a) (b)

Figure 9. Overviews of the two rock temples (a) Yinxian Rock (b) Huayang Rock

The orientation of the cave openings and the prevailing wind direction together influence the magnitude of the wind direction projection angle. The wind direction projection angle is the angle between the wind direction projection line and the normal line of the building wall. For these two temples, the wall direction corresponds to the direction perpendicular to the opening. It is known that the ventilation volume is related to the wind direction projection angle. A smaller wind direction projection angle results in a larger ventilation volume through the opening. As the wind direction projection angle increases, the wind speed inside the cave decreases, which is not conducive to ventilation [17]. The orientation of Yinxian Rock's cave faces east (91° clockwise from the true north), aligning with its prevailing wind direction. Therefore, theoretically, most of the wind can blow directly into the temple's opening, with a wind direction projection angle close to zero, achieving maximum ventilation, as shown in **Figure 10(a)**. This allows the wind to form a complete circulation path inside the cave.

On the other hand, the orientation of Huayang Rock's cave is roughly southwest (212° clockwise from the true north), which deviates from its prevailing west wind, resulting in a reduced ventilation volume due to the wind direction projection angle, as illustrated in **Figure 10(b)**. When the west wind blows into the cave, it is difficult for the wind to flow into the areas on both sides of the temple, creating two windless zones.



(b)

Figure 10. Schematic diagram of wind circulation inside (a) Yinxian Rock and (b) Huayang Rock

In summary, after comparing factors affecting the ventilation environment, such as wind direction and speed, surrounding environment, and cave opening formation, between the two temples, it can be concluded that Huayang Rock's ventilation environment has many disadvantages compared to Yinxian Rock in various aspects. To improve its poor ventilation environment and slow down the damage rate of the temple, the following section will adopt numerical simulation of the wind environment to simulate the ventilation conditions of Huayang Rock when subjected to winds from different directions and magnitudes. By varying the wind direction and speed, we aim to find an ideal ventilation effect, providing methodological support for future preventive protection plans.

3. Numerical simulation of wind environment in Huayang Rock

Wind speed provides a direct indication of the ventilation status within an environment. Additionally, a larger wind pressure difference suggests better wind pressure ventilation within the temple [17]. The wind vector diagram illustrates the amount of ventilation and the internal movement path of the wind. These three indicators can collectively assess the general ventilation conditions of the temple's microenvironment within the cave. The simulation software used in this paper is PHOENICS, which can simulate the instantaneous values of wind speed, direction, and pressure at various points on a plane for buildings and environments, presenting clear and intuitive graphical results. Considering local environmental data, these instantaneous values represent the average of hourly calculation results. For the PHOENICS settings, the template is selected as FLAIR, the energy equation focuses on temperature, the turbulence model is Chen-Kim KE, and the profile type is Power Law. Wind speed and direction are set according to simulation requirements, while the temperature parameter is set to 20°C without considering the influence of solar radiation. The environmental wind speed settings are based on local meteorological data from November 1, 2022, to February 28, 2023.

3.1. Ventilation conditions of Huayang Rock under different wind directions

Since the general orientation of Huayang Rock is southwest, there are four types of winds that can flow into the cave entrance: northwest wind, west wind, southwest wind, and south wind. The remaining directions are similar to the temple's orientation and have a minimal impact, so they are not considered. When testing different wind directions, the wind speed is set to 2 m/s, which is more in line with the site environment [17]. **Figure 11** shows that the wind pressure generated when the wind direction is southwest is the highest, with approximately 1.51 Pa at the entrance, and the pressure difference with the rock wall is also the largest among the four wind directions. Therefore, its wind pressure ventilation conditions are the best, which aligns with theoretical expectations. The west wind follows, and the northwest wind has the smallest pressure difference, almost zero, indicating the poorest wind pressure ventilation conditions.

Regarding wind speed, it is evident that the south wind environment produces the highest wind speeds. The highest wind speeds within the temple are located at the entrance and the southwest corner of the building, where the building's preservation status is also the best. The wind speeds for the other three wind directions are relatively low, consistent with actual measurements. Surprisingly, the wind speed around the rock wall in a southwest wind environment directly facing the temple opening is the lowest, contradicting theoretical expectations. Since Huayang Rock experiences less south wind in actual measurements, but the wind speed blown into Huayang Rock under the south wind is the highest among the four wind directions, increasing south wind could be considered.

The wind direction vector diagram reveals that the northwest wind does not blow into the cave. The cave's formation in Huayang Rock alters the wind direction, preventing it from flowing into the cave. More winds from the southwest and south directions flow into the cave, with the southwest wind being the most prominent. Based on wind pressure difference, wind speed, and ventilation volume, it can be generally inferred that under the same wind speed, the temple experiences the best ventilation effects from the south and southwest winds.

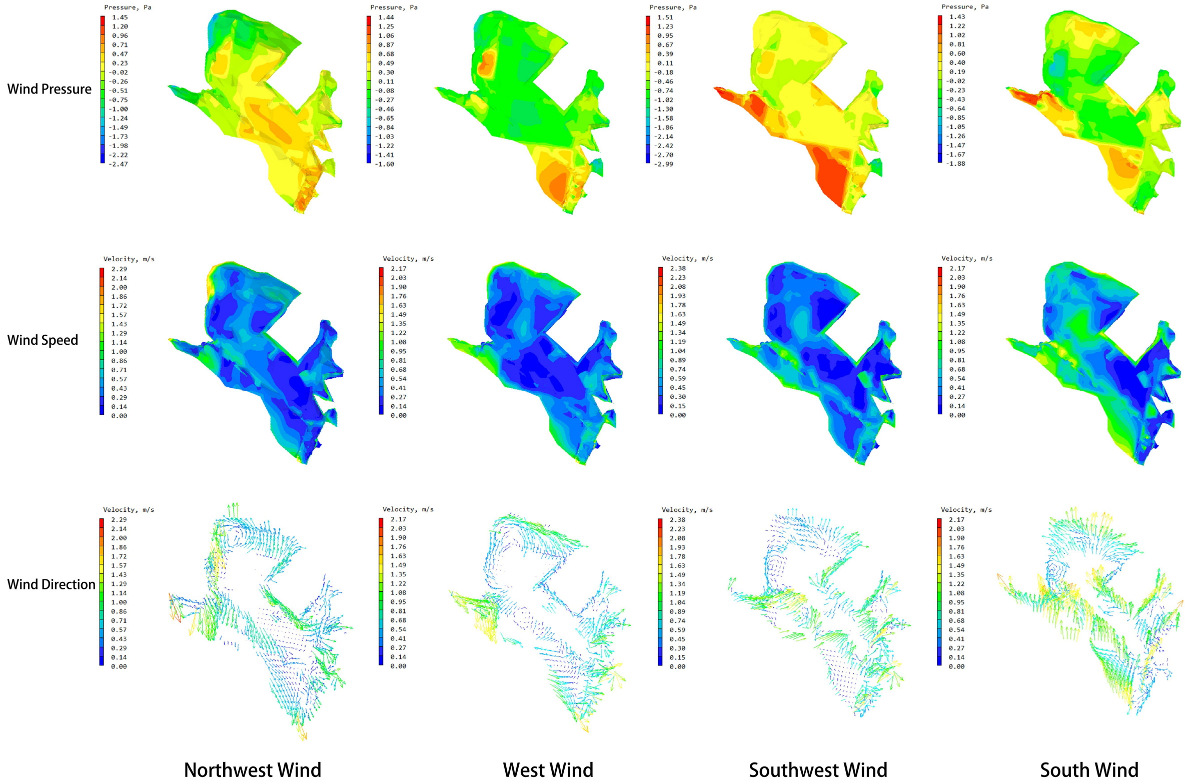


Figure 11. Comparison of different wind directions at 2 m/s wind speed

3.2. Ventilation conditions at different wind speeds under south and southwest winds

Wind speed is not necessarily better when it is higher. Although wind can reduce moisture on building surfaces, excessively strong winds can also increase the probability of weathering, so an appropriate wind speed is crucial to achieve the best effect. Based on the above conclusions, this study selected south and southwest winds to simulate the ventilation effects of Huayang Rock under these wind directions at different wind speeds. The wind speeds were set to 2 m/s, 5 m/s, and 10 m/s, representing the range from a breeze to a light breeze and then to a moderate breeze. The simulation results of internal wind pressure, wind speed, and wind vector diagrams were compared to determine which range of wind speeds could achieve better ventilation effects.

The figures show that when Huayang Rock is subjected to south winds of different strengths, the distribution of wind pressure and wind speed inside the cave does not undergo significant changes as the wind speed increases, except for numerical increases. The wind vector diagram reveals a vortex wind area in front of the rock temple and the cave entrance at a wind speed of 5 m/s, which disappears when the wind speed increases to 10 m/s. Overall, among the three scenarios, the ventilation conditions are best at a wind speed of 5 m/s, with an average internal wind speed of 2–3 m/s, which is an ideal situation.

Similarly, the simulation results for southwest winds at 2 m/s, 5 m/s, and 10 m/s are shown in the figures. It can be seen that the distribution of wind pressure at a wind speed of 5 m/s is different from the other two conditions. The wind pressure difference between the front of the cave and the front of the rock temple decreases, and the increase in wind pressure at the front of the rock temple becomes larger, without forming a positive and negative pressure difference. At 10 m/s, the wind pressure in this area changes from positive to negative, and the area close to the rock wall becomes positively pressurized, with wind blowing from the rock wall to the cave entrance. A large difference in wind pressure is formed between the cave entrance and the front of the rock temple, with the red area ranging from 32 Pa to 38 Pa and the green area ranging from -11 Pa to -5 Pa. The wind pressure ventilation is greatly improved in the area front of the south facade of the rock temple, and the wind pressure on both sides of the rock temple also becomes negative, with wind blowing from the rock wall to both sides of the rock temple.

In terms of wind speed, it can be observed that as the wind speed increases, the wind speed inside the cave does not increase significantly as it does under south wind conditions. When the wind speed reaches 5 m/s, the average wind speed inside the cave remains around 0–2 m/s, which is not ideal. When the wind speed increases to 10 m/s, except for a significant increase in wind speed in the southwest corner of the building, the wind speed on the three sides of the rock temple building actually decreases.

From the wind vector diagrams under the three conditions, it can be seen that when the wind speed is also 5 m/s, a small area of wind vortex forms in front of the rock temple, and there is a significant rebound of wind speed. When the wind speed reaches 10 m/s, similar to the south wind situation, more wind blows into the cave, but the vortex area in front of the cave disappears, and a new vortex forms in the southeast corner of the cave entrance. Overall, the ventilation effect is best when the wind speed is 10 m/s under southwest winds, which corresponds to a moderate breeze.

The above analysis indicates that Huayang Rock has better ventilation effects when subjected to southwest and south winds. Under south wind conditions, when the wind speed is 5 m/s, a more pronounced circulating wind can form in front of the rock temple. The best ventilation effect is achieved when the southwest wind speed is 10 m/s, creating a wind pressure ventilation effect where wind flows from positive to negative pressure on all three sides of the rock temple.

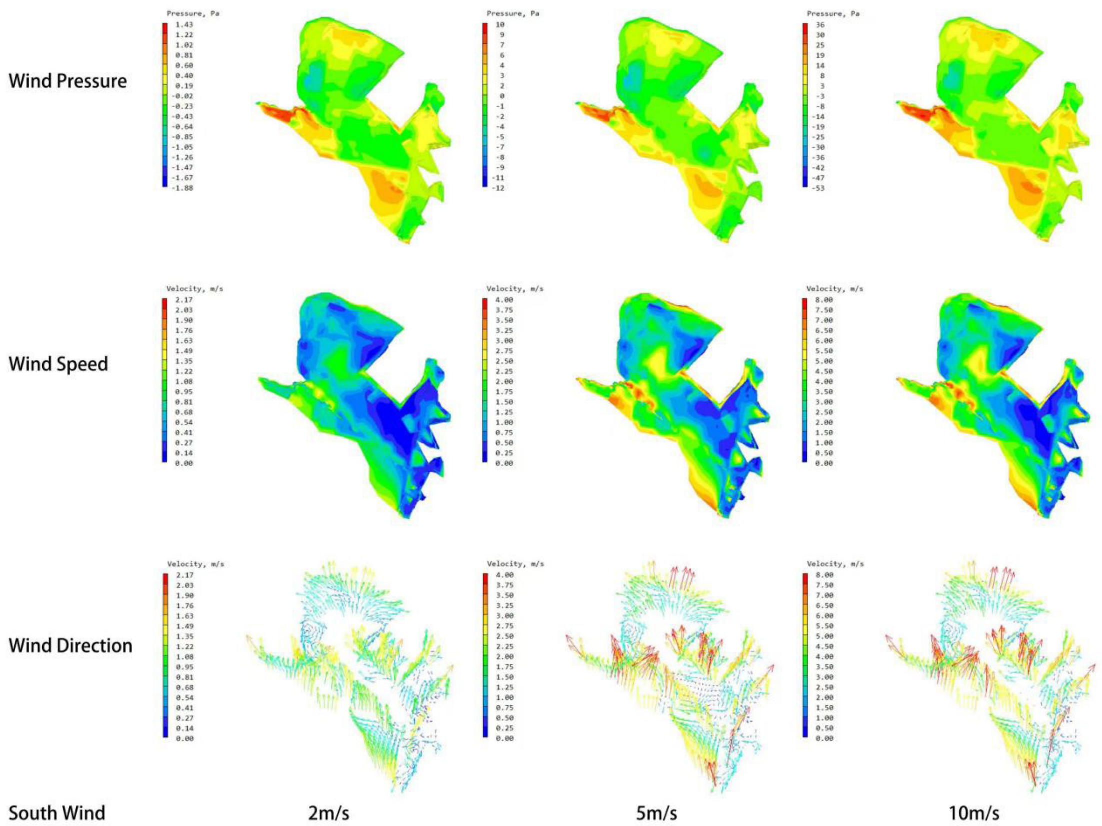


Figure 12. Comparison of different wind speeds under south wind direction

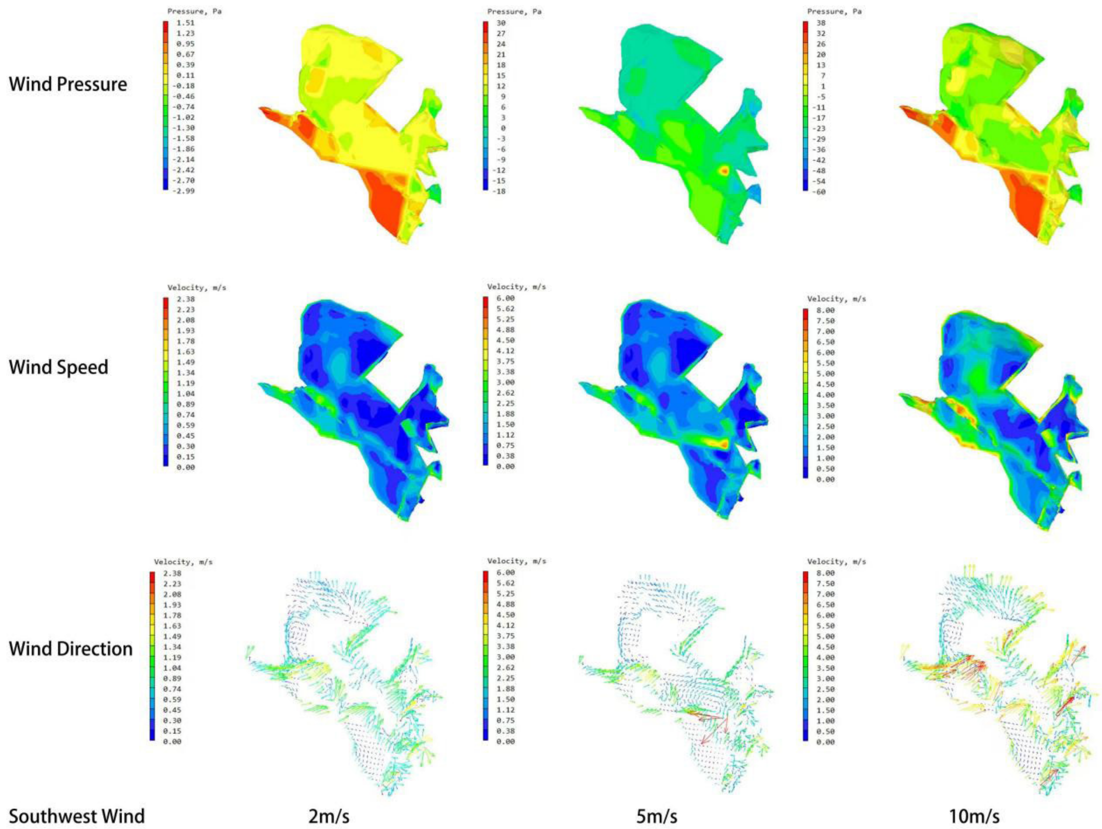


Figure 13. Comparison of different wind speeds under southwest wind direction

4. Concept of preventive protection plan

After simulating the wind environment of Huayang Rock under different wind directions and speeds and identifying several favorable scenarios, we hope to achieve similar effects through implementable solutions, providing a generally feasible direction for the preventive protection of Huayang Rock in the future. Preventive protection methods for cultural relic buildings are mainly divided into active and passive measures. For Huayang Rock, which has a poor ventilation environment, active measures for wind pressure ventilation mainly include active air supply and extraction, such as using mechanical equipment like blowers to increase the wind speed within the building's microenvironment.

Passive regulation refers to methods that can achieve physical environmental control without the intervention of mechanical equipment. Compared to active regulation, this approach is less likely to cause secondary damage to cultural relics, so it can be prioritized for intervening and regulating the environment of Huayang Rock. One method is to appropriately remove environmental obstacles that block Huayang Rock, such as surrounding trees and stone railings, to reduce wind resistance. Another approach is to place windshields in front of the cave to alter the wind direction. Based on simulation results, the ambient wind can be largely converted into south and southwest winds to increase ventilation. This method is currently one of the most feasible options. Since the wind speed at the entrance of Huayang Rock is already low, merely changing the wind direction may not yield significant results. It is necessary to increase the overall wind speed before altering the direction to achieve more uniform wind distribution and optimal effects. Additionally, there is a more challenging method that involves greater intervention in the current environmental state, which is to seal the cave entrance, increase the temperature difference between the indoor and outdoor environments, or directly remove moisture from inside the cave to enhance the thermal pressure ventilation of Huayang Rock.

Considering the various aspects of Huayang Rock's wind environment that are unfavorable to the cave itself, it is necessary to intervene and regulate factors such as wind speed, wind direction, and environmental obstacles. A combination of active and passive measures, with active measures as the primary approach and passive measures as a complement, can achieve the best results through a multi-mode integrated approach.

5. Conclusion

This paper starts from observing the phenomenon of different architectural issue severities in two rock temples on Wudang Mountain: Yinxian Rock and Huayang Rock. It explores the correlation between the causes of the architectural issues and their environmental conditions. After comparing and monitoring the wind environments of the two rock temples, it concludes that the wind speed at Yinxian Rock is much higher than that at Huayang Rock, and its orientation aligns with the prevailing wind direction, which is eastward. On the other hand, Huayang Rock faces southwest, deviating from the prevailing westerly wind. By analyzing their surrounding environments and cave formations, it is determined that Huayang Rock has a poorer ventilation environment compared to Yinxian Rock.

To improve the inadequate ventilation at Huayang Rock, microenvironment wind pressure, wind speed, and wind vector diagrams were simulated under different wind directions and speeds. Several scenarios with better ventilation effects were identified, specifically when the wind speed is 5 m/s from the south and 10 m/s from the southwest. Based on these findings, several general directions for preventive protection are proposed.

This paper primarily considers wind environmental factors in analyzing the causes of architectural issues in the two rock temples, while neglecting other potential influencing factors such as humidity and carbon dioxide concentration. Additionally, the simulation conditions are relatively idealized and may not fully reflect the actual situation. Future research will incorporate more possible environmental factors and introduce more realistic variables into the environmental simulation, aiming to closely approximate the real environmental conditions and enhance the accuracy and feasibility of the simulation results.

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