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THERMAL ENVIRONMENT IN AJANTA CAVES

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Introduction

This paper reports the thermal environment throughout the year in the Ajanta Caves, India, with a focus on the influence of visitors. Ajanta is located at 20º north latitude and 75º east longitude in west-central India. The Ajanta Caves include about 30 caves which have richly decorated murals dating from the 6th century BCE to the 2nd century CE (Figures 1 and 2).

These murals have suffered from several causes of damage such as insects, small animals, and water [1]. An unsuitable thermal environment in the caves could be a factor that causes deterioration of the murals. Humidity changes in particular cause damage. High humidity causes damage to the plaster due to increased insect population, and wet and dry cycles cause cracks and loss of the surface of the paintings.

When the caves are open, the outside environment influences temperature and humidity in the caves. Nowadays, the cave openings are closed to prevent small animals from entering the caves; thus, the influence of the outside environment has become less. However, the influence of visitors is noticeable as a factor that increases temperature and humidity in the caves. To conserve the murals, it would be simple to close the caves to the public. However, the effective use of this cultural heritage for the development of the surrounding area requires public access. It is important to control the visitors in order to maintain a balance between sustainable development and conservation of this cultural heritage.

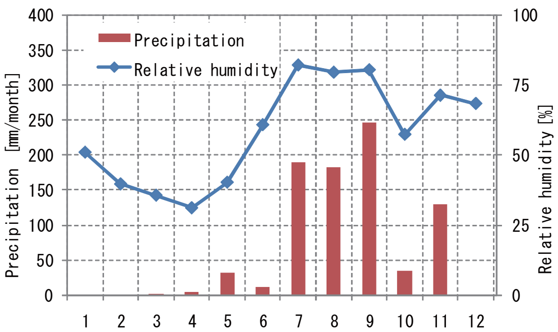
In the present paper, the temperature and humidity in the caves are discussed focusing on those caves open to the public.

Figure 1 View of the Ajanta Caves

Figure 2 Site plan of the Ajanta Caves

1. Annual local climate

There are three seasons in this area: the rainy season, the dry season, and the hot season. Monthly rainfall is over 150 mm/month from July to September (Figure 3 left) [2]. Temperatures in April are the highest for the year with a monthly average temperature of 32 ºC and a daily maximum temperature of over 40 ºC. January temperatures are the lowest of the year with a monthly average temperature of 23 ºC and a daily minimum temperature of 13 ºC (Figure 3 right). The daily average relative humidity is 80% in the rainy season and 40% in the dry season (Figure 3 left). The changes in the temperature and humidity of the surrounding environment are very large.



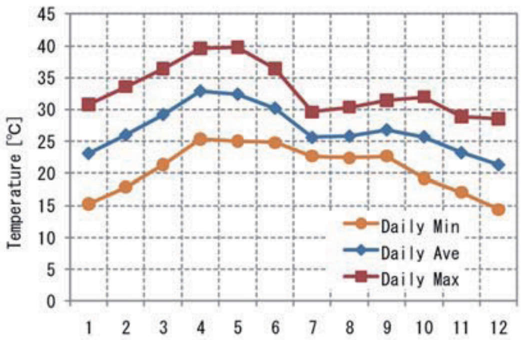


Figure 3 Local climate (left: relative humidity and precipitation, right: temperature)

2. Condition of the murals and the thermal environment

The factors causing the deterioration of the mural paintings in the Ajanta Caves are damage from rain water, a black substance related to bat excreta, insects and small animals, and deterioration of the materials used in past conservation treatments [1, 3].

Humidity changes accelerate deterioration of the mural paintings. For example, because the black substance related to bat excreta has high moisture absorbency, it undergoes repeated expansion and contraction whenever the humidity changes. As a result, humidity changes cause flaking of the paintings. Further, under high-humidity conditions, insects such as silverfish infest the plaster layers supporting the paintings [3]. The dry and wet cycle of humidity causes the expansion and contraction of the plaster, causing the plaster to detach from the back walls. In low-humidity conditions, the paint binder becomes friable, and the paintings detach from the walls. Thus humidity changes influence the condition of the mural paintings.

These damages to the mural paintings develop on the front side, where the outside environmental changes are larger than those on the back side. Nowadays, because the openings are closed to prevent small animals such as bats entering the cave, the influence by outside changes has become small. Now, however, the temperature and humidity increase caused by visitors has become a concern.

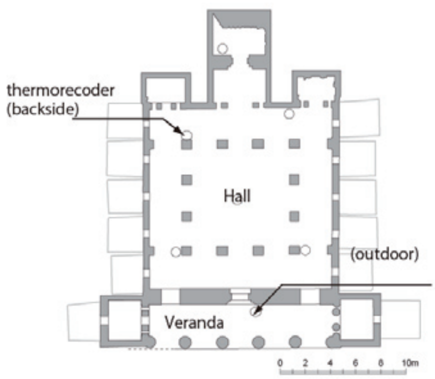


Figure 4 Plan of Cave 2

3. Environmental survey in Cave II

Measurements of the temperature and humidity by thermo recorders have been conducted at several points in Cave II since 2009. Cave II is located near the entrance to the Ajanta Caves (Figure 2) and consists of the terrace, main room, and small sub rooms (Figure 4). In the past, all of the walls and ceilings were covered by paintings.

3-1. Inside and outside temperature and humidity

The outside temperature becomes highest in April and lowest in January. However, the temperature in the caves becomes highest between May and June, which lags the changes in the outside temperature (Figure 3 right). The daily range of outside temperatures is small from June to September, and large from March to May and from October to December. The outside yearly variation is 5 ºC, and inside it is 0.5 ºC. The influence of the outside daily temperature change on the inside condition is small.

When the outside humidity is high between June and September, the inside humidity is close to that outside. When the outside humidity is low, the inside humidity is slightly higher than outside. This might be due to water sources in the cave.

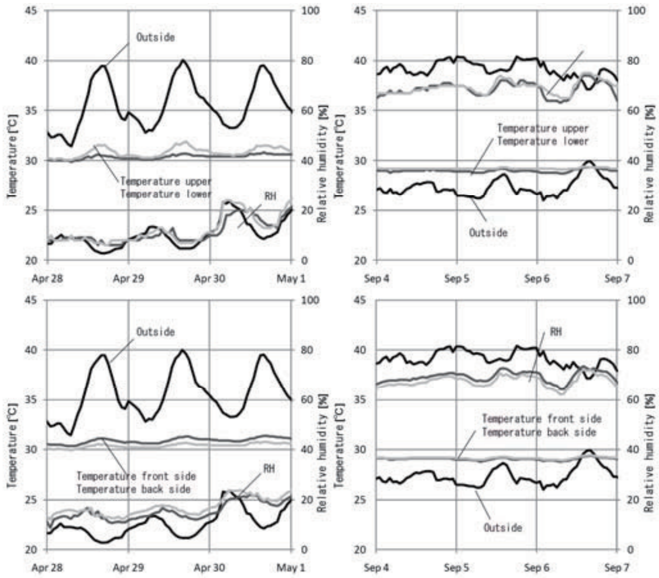


Figure 5 Temperature and relative humidity in Cave 2

(Left: April, Right: September)

The daily ranges of both temperature and humidity inside the cave are smaller than outside. The differences in the temperature and humidity from April to September are large: 10 ºC in temperature and 60 points in relative humidity.

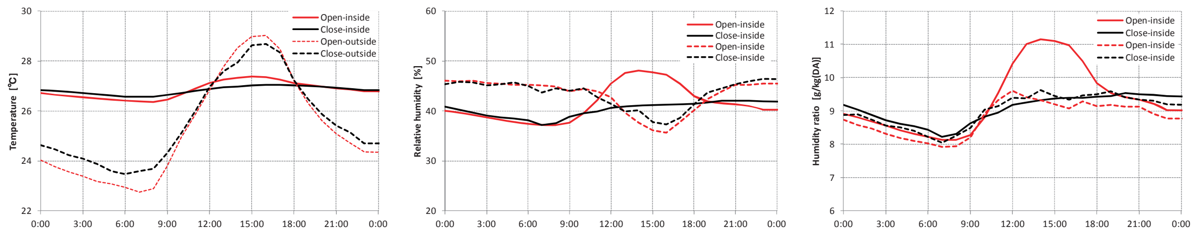
Comparing the temperatures upper and lower sides (Figure 5), the changes in the temperature upper side are greater than the changes in the temperature lower side. Particularly, the temperature change upper side is greater when the outside temperature is high, and that temperature change lower side is greater when the outside temperature low. The temperature difference between the front and back areas is smaller than that between upper and lower sides. The temperature at the front side is 0.5 ºC higher than that at the back side. The differences in both the relative humidity and humidity ratio between front side and back side are small, and the humidity ratio is almost same as outside.

3-2. Temperature and humidity at the opening and closing days

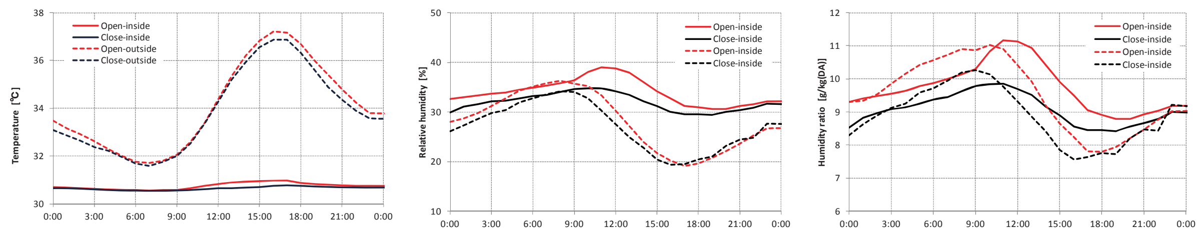
On a busy day, over 1500 visitors come to the caves. On a slow day, there are about 500 visitors. The open hours are from 9:00 to 17:00. If the average person stays for 15 minutes in the cave, there are on average 10 to 30 visitors inside the cave all of the time.

The temperatures at night for both open days and closed days are almost the same. While the daytime temperature on open days is 0.1–0.3 ºC higher than that on closed days (Figure 6). This increase in temperature has been confirmed in all seasons. The difference in the dry season is greater even though the outside temperature is lower.

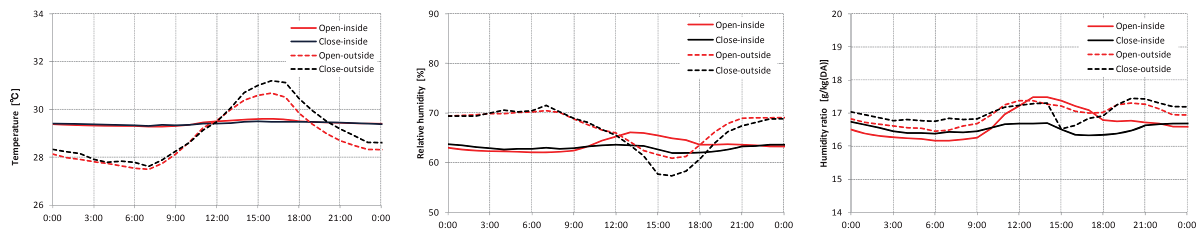
The changes in the humidity ratios denote the same tendency as the changes in temperature. The humidity ratio from 9:00 to 14:00 on open days increases greatly. The maximum difference between open days and closed days is 1.6 g/kg (DA). The changes in the humidity ratios are also shown for the rainy season and the hot season. The difference is greater on Sundays and Tuesdays when many visitors come to the caves.



(a) Dry season (December to February)



(b) Hot season (April to June)



(c) Wet season (July to September)

Figure 6 Comparison between inside and outside of temperature, relative humidity and humidity ratio

4. Influence of visitors

In order to evaluate an influence of the visitors on the thermal environment in the cave, the numerical calculation of air temperature and humidity ratio in the cave is conducted. This calculation includes the heat and moisture transfer in the porous materials. The equations (1) and (2) show the heat and moisture balances of the air in the cave. The heat and moisture flows from the surrounding walls, ceilings and floor, ventilation between inside and outside and generations from human are considered. The equations (3) (4) show heat and moisture balances in the porous materials. One third of all wall and ceilings surfaces are assumed to be covered with the mortar which is porous material. The surface of the floor is assumed to non-permeable to vapor. The air exchange volumes are decided as a function of the temperature differences between inside and outside. The temperature and humidity ratio measured from March 2009 to March 2010 in the veranda is used as the outside condition. The average temperature and humidity ratio are used as initial conditions, and the ground temperature and humidity ratio at a depth of 10 m is assumed to be the same as the average values of the outside.

Figure 8 shows the comparison of the calculated temperature and humidity ratio in the cave of both closed and open days on one day in March. There are 30 visitors per hour (1500 visitors per an open day). The differences daily maximum and daily minimum of the temperature and humidity ratio on open day are larger than those on closed day. These differences of the temperature and the humidity ratio were about 0.5 ºC and about 0.6 g/kg(DA). The temperature and humidity ratio on open day are higher than that on closed day through the year.

$$c_a \gamma_a V_{cave} \frac{\partial \theta}{\partial t} = Qw + Qg + Qv + Qh \quad (1)$$

$$\gamma_a V_{cave} \frac{\partial X}{\partial t} = Mw + Mg + Mv + Mh \quad (2)$$

$$(c'\gamma' + \kappa) \frac{\partial X}{\partial t} = \lambda' \frac{\partial^2 X}{\partial x^2} + \upsilon \frac{\partial \theta}{\partial t} \quad (3)$$

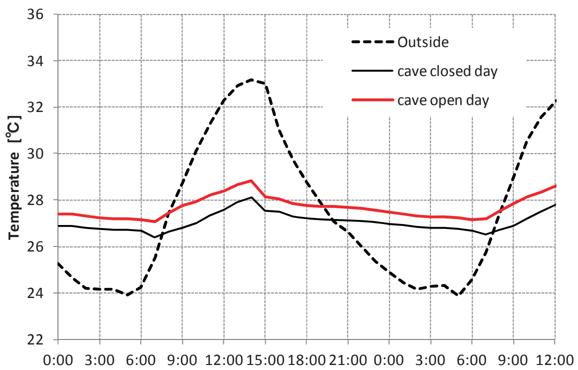
$$(c\gamma + R\upsilon) \frac{\partial \theta}{\partial t} = \lambda \frac{\partial^2 \theta}{\partial x^2} + R\kappa \frac{\partial X}{\partial t} \quad (4)$$

Symbles

c:specific heat [J/kgK], c':porosity [m^3/m^3], M:moisture flux [kg/s], Q:heat flux [W], R:heat of adsorption [J/kg K], t: time [s]; V: volume [m^3], X: humidity ratio [kg/kg(DA)], x:distance into wall [m], α:heat transfer coefficient [J/m^{2}sK], α':moisture transfer coefficient [kg/m^{2}s (kg/kg(DA))], γ:density [kg/m^3], θ:temperature [degrees C], κ:amount of absorption and desorption of porous material per humidity ratio [kg/(m^3(kg/kg(DA))], λ:thermal conductivity [W/m K], λ':moisture conductivity associated with a moisture content gradient [kg/mh (kg/kg')], ν: amount of absorption and desorption per unit of temperature, [kg/(m^{3}K)], ρ:density [kg/m^3],ω: rate of moisture content [kg/m^3].

Subscripts

a:air, cave: cave, g: ground, h: human, v:ventilation between outside and cave, w:wall.



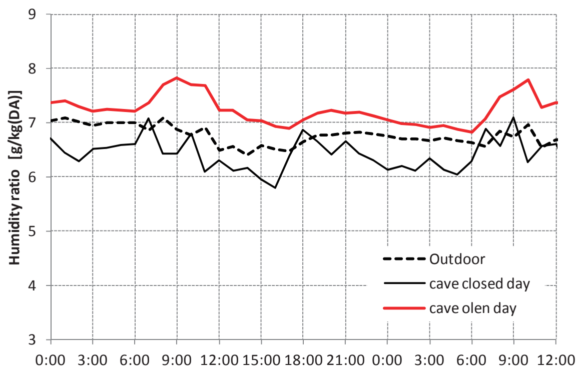


Figure 7 Calculated temperature and humidity ratio

5. Conclusion

In order to conserve the historical site with the sustainable development, the control of the thermal environment is required. In this paper, the thermal environment in the Ajanta Caves and the influence of the visitors on the caves environment are discussed.

Acknowledgment

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References

[1] Sharma, P.K., 2006. 'Painting techniques and materials of cave murals in India and their conservation problems', Murals of the Silk Road: Culture exchange between East and West, Proceedings of the 29th Annual International Symposium on the Conservation and Restoration of Cultural Property, National Research Institute for Cultural Properties, Tokyo: 101-106. Archetype publications.

[2] NRICP・ASI: Indo-Japanese Project for the Conservation of Ajanta Paintings, 2008, Indo-Japanese Project for the Conservation of Cultural heritage, Series 1, JCICC, NRICP, 2010.

[3] Tilak, S.T., Sharma, B.R.N., Sengputa, S.R., and Kulkarni, R.L. 1970. 'The deterioration and microbiological studies of Ajanta and Ellora paintings', Conservation of cultural Property in India, Vol. 5 (1970), Indian Association for Study of Conservation of Cultural Property, New Delhi: 77-82.