An experimental study on the improvement of indoor thermal environment of tents by shading in summer

Yingni Jiang1, Xinxiao Chen2,*

1 Institute of equipment management and support, Engineering University of CAPF, Xi’an 710086, China
2 Shaanxi Key Laboratory of Safety and Durability of Concrete Structures, Xijing University, Xi’an 710123, China

*Corresponding author e-mail: 13772146702@163.com

Abstract. Because of the simple structure and easy to carry, tents are widely used in military camps, rescue and disaster relief, site construction, tourism, nomadic people living and so on. However, the tent is very hot and humid in summer which seriously affects people’s rest and work. By the method of erecting a shading net on the top of the tent, the influence of solar radiation on the indoor thermal environment of tents in summer can be reduced. The indoor thermal environment of tents with different density shading nets was tested at a university campus of Tianjin, China. The experimental results showed that, comparing with the tent with no shading, the cooling effect of "six pins" net with shading rate of 96% is very good, the indoor temperature of the tent in summer can drop 8°C; while the indoor temperature of tent shaded by "three pins" net with shading rate of 75% can drop 5°C. The results also showed that: the internal surface temperature of the tent with shading nets can decrease about 12~17°C, the cooling effect is very obvious. The sun shading is conducive to improve the thermal environment of the tent.

1. Introduction

As a simple temporary building, tent can isolate relatively safe and independent space in the field for people to rest and live. It can protect against rain, snow, sunlight, coldness, wind and mosquito. Because of its unique features such as dismantling, transportation, convenience and fast moving, tent plays an irreplaceable role in army camping, earthquake relief, tourism exploration and herdsmen nomadic.

However, because the tent's enclosure structure is simple and light, it usually can not guarantee the comfort. It is mainly manifested in the following two aspects: First, the indoor temperature is seriously affected by the outdoor environment. The indoor temperature varies with temperature outside and rises rapidly with direct sunlight. The indoor temperature of tent can exceed 40 degrees in summer, much higher than that outside, which is not suitable for people to rest. The temperature under the roof in summer even exceeds 50 degrees. The indoor temperature drops at night with the temperature outside. The wide fluctuation in temperature causes a strong sense of discomfort. Second, the indoor humidity is seriously affected by the outdoor humidity. The moist air in the field is easy to get inside, and many tents don’t have groundsheets, the ground moisture also increases the indoor humidity. It's hard for people in this environment to rest well.
In recent years, with the continuous improvement of technological innovation, the research and design of tent has gained more attention and development. Many new tents and professional tents came into being. Also improving thermal environment inside tents has attracted considerable research interests worldwide. Scholars at home and abroad studied the structure of tent [1-4], the tent material [5-9], spraying [10], aluminum foil and watering method [11]. In addition, an experimental study on the indoor thermal environments in an experimental prefabricated houses was reported, which has the same characteristics of thin structure with the tents [12]. But until now, few experts and scholars applied the shading technology to improve the indoor thermal environment of the tent. In this paper, the shading nets of different knitting density were used to improve the thermal environment of tents by experimental study, providing a reference for the cooling of the tent in the summer.

2. Experimental tents and measurement details

2.1. Experimental tents and shading nets

The experiment was done on a university campus of Tianjin. The experimental tents are three cotton tents with green color. The length of the tent is 4.4m, the width is 4.6m, the ridge height is 2.57m and the eaves height is 1.4m. There are two windows on both the front wall and the back wall. And there is a door on one of the gable walls. The surface material is polyester waterproof canvas of green color, the interior material is white Oxford cloth.

Ordinary agricultural shading net was used to do the experiment. It has good practicability in shading and cooling, etc. The color is usually black or green and the knitting density is "three pins", "four pins" and "six pins", respectively. Generally speaking, the higher the knitting density of net, the better the shading effect, but the ventilation effect of the net will decrease. In this paper, a black "three pins" net (shading rate = 75%) with the area of 10m*10m and a black "six pins" net (shading rate >96%) with the area of 10m*10m were selected to contrast the cooling effect.

The three experimental cotton tents were arranged on an open space of the campus. The site was selected to avoid the block of the wind or sunshine by buildings and trees. The tents were arranged on the open space from east to west with a distance of about 15m. The door faced east and the windows faced north and south. All the doors and windows were open in the experiment. To study the cooling effect of different nets, the tent in the extreme west side was shaded by a "six pins" net, the tent in the middle was shaded by a "three pins" net, and the tent in the most east had no shading.

The shading nets were raised on the top of the tents by eight columns of 4.5 meters high, and the shading nets were 1 meter higher than the roofs of the tents. Because the tent covers an area of 4.4m*4.6m and the shading net has a 10m*10m shading area, the net can cover the entire tent from the direct sunlight during 10:00-14:00 period. The experimental tents with shading nets are shown in Fig.1.

2.2. Measurement details

In order to know the temperature field inside the tents, the temperatures were measured in the tents. Mercury thermometers and globe thermometers were used as the experimental instruments. The measuring range of the mercury thermometer is 0-50°C, with an accuracy of 0.1°C. The measuring range of the WBGT index of the globe thermometer is also 0-50°C with an accuracy of 0.1°C. 23 thermometers were hung in every tent. In five locations of the southeast, southwest, northwest, northeast and central, 4 thermometers were hung at the height of 0.1m, 0.5m, 1.0m and 1.5m, respectively. Fig.2 shows the position of temperature measuring points at the measuring height. In addition, 3 thermometers were added under the roof of the tent at the height of 2.0m in order to measure the temperature under the roof of the tent. The measurement was carried out during the period of 7:30 - 17:30 on June 29, 2016. The measurement time interval was an hour. The weather was sometimes cloudy and sometimes sunny in the morning. After 14:00 it was completely cloudy and the solar radiation decreased gradually.
3. Measured results of indoor thermal environment in the experimental tents

3.1. Temperatures at different heights

Many thermometers were hung at different heights in the tents, and the recorded data were averaged at different heights. Fig. 3-5 show the temperature results inside the tents with different shading nets.

**Figure 1.** The experimental tents with shading nets.

**Figure 2.** The arrangement of the mercury thermometers in the tent.

**Figure 3.** Comparison of the average temperatures at different heights in the tent without shading.

**Figure 4.** Comparison of the average temperatures at different heights in the tent shaded by a "three pins" net.
Figure 5. Comparison of the average temperatures at different heights in the tent shaded by a "six pins" net.

It can be seen from Fig. 3 that the temperature inside the tent changed obviously with the outdoor solar radiation. The peak temperatures appeared at 9:30 and 13:30 at 2m height respectively. The highest temperature is 41.8°C and it’s very hot in the tent. The temperature trough (lower than 35°C) appeared at 10:30 because it’s cloudy outside now. After 15:00, the temperature gradually declined. It can also be seen from the figure that the higher the height, the greater the temperature changes and the lower the height, the flatter the temperature fluctuation. It shows that the closer to the roof of the tent, the greater the temperature affected by the outside, and the temperature increases or decreases greater than other places. During the period of 7:30 - 13:30, the temperature curves at 0.1m, 0.5m and 1.0m fluctuated slightly and gradually increased, which showed that the heat dissipation ability of the tent was poor, the internal heat continued to gather, and the temperature increased.

Fig. 4 shows the comparison of the average temperatures at different height in the tent shaded by a "three pins" net. It has the same temperature variation characteristics as the tent with no shading. That is, the higher the height, the greater the temperature affected by the outside. And the temperature changes with the weather especially the solar radiation. The peak temperature (33.6°C) is smaller than that of the tent with no shading. Although the tent temperatures have the same change trend, the inside temperature of the tent shaded by a “three pins” net increased more slightly than the tent with no shading because of the effect of the shading net.

Fig. 5 shows more clearly the effect of shading on temperature fluctuation of the tent. The shading effect of “six pins” net is the best, there is no large fluctuation for the temperature. Before 13:30, the temperature rose slowly. The temperature peak appeared at 13:30 at 2m height. After 13:30, the temperature gradually decreased with the decrease of solar radiation. The peak temperature got minimum (32.5°C) of the three tents, which illustrated that the greater the shading net knitting density, the stronger keeping out the radiation from the sun, the better the sun shading effect.

The three figures show the same internal temperature field characteristics of tents. Firstly, the greater the height is, the higher the temperature. The 2.0m height temperature can exceed 40°C even be close to 42°C in the ordinary tent without shading, while the temperature of 0.1m layer is not greater than 34°C. The tent shaded by nets also have this characteristic, just the temperature differences are small. Secondly, the greater the height is, the greater the temperature fluctuation, especially in the ordinary tent without shading.

3.2. Internal surface temperatures

The temperatures of the internal surfaces of the tents were tested with an infrared thermometer every an hour. Fig. 6-8 show the results of the three experimental tents under different shading conditions.
Figure 6. The internal surface temperatures of the tent without shading.

Figure 7. The internal surface temperatures of the tent shaded by a "three pins" net.

Figure 8. The internal surface temperatures of the tent shaded by a "six pins" net.

It can be seen from Fig.6 that the most obvious characteristic of the tent with no shading is the top surface temperature is very high. During 10:00 - 14:00, the temperature is about 45°C, and the highest temperature is close to 50°C. The tent absorbed a lot of solar radiation which led to the high temperature. During 8:00-11:00, the eastern wall temperature is high because in the morning the sun radiation comes from the east. After 13:00, the west internal surface temperature is high, the main reason is the change of the direction of the sun, the west wall is influenced by solar radiation. The tent bottom surface temperature is the lowest, keeps at 30°C-35°C most of the time. Although it is lower than other wall temperatures, it is still higher than the temperature of the human body comfort.

It can be seen from Fig.7 that by erecting a “three pins” net at the top of the tent, the top surface temperature of the tent greatly reduced. The highest temperature is about 38°C, which is about 12°C lower than that of the tent without shading, the temperature difference is very obvious. Because of the shading position and shading area limitations, during 8:00 - 10:00, the shading net can not block the
solar radiation on the east wall, the east wall temperature is high. While during 10:00 - 11:00, the shading net plays a great role in blocking the sun radiation on the eastern wall, so the east wall temperature decreased. At 14:00, the west wall temperature is high, the reason is also the net set at the top of the tent can not block all the solar radiation from the west side. The bottom surface temperature is the lowest and fluctuates at 29℃.

It can be seen from Fig. 8 that setting up a “six pins” net at the top of the tent makes the wall temperature curve of the tent getting closer. Especially during 10:00-14:00 period, the wall temperature difference does not exceed 2℃ except for the bottom surface. This indicates the shading net plays a great role in blocking the tent wall from the sun radiation in this period. From the top surface temperature curve, the temperature is not very high, the highest temperature is about 33℃. The difference between the top surface temperature of the tent without shading and the tent shading with a “six pins” net is nearly 17℃. It can be seen that the cooling effect of the “six pins” net is very obvious. Before 10:00, the east wall temperature is the highest, after 14:00 the west wall temperature is the highest, the main reason is also that shading net is not large enough to block the solar radiation from the east and west sides. The bottom temperature is low, fluctuates at 27℃, and the temperature is lower than the tent without shading and the tent shading with the “three pins” net.

The internal surface temperatures of the three tents have the following characteristics. The first is the temperatures increased with the solar radiation. When it was sunny, the temperatures were high. When it was cloudy, the temperatures were low. The temperatures gradually decreased after 14:00 along with the solar radiation. The internal surface temperatures of the tent without shading changed more greatly than the tents with shading. The second is in the morning the east wall temperature is high and in the afternoon the west wall temperature is high. The main influencing factor is the solar radiation, and the shading net can not block the radiation on both sides. It is recommended to enhance the sun shading on sides of the east, the west and even the south, which can lower the solar radiation and reduce the indoor temperature. The third is the top surface temperature is the highest for the tent without shading and the tent shaded by a “three pins” net. But because of the high shading rate, the top surface temperature of the tent shaded by the “six pins” net is at an intermediate level among its internal surface temperatures. The fourth is the bottom surface temperature is the lowest, generally lower than the other surface temperatures by 3℃-5℃, and with the increase of sun shading rate of the net, the bottom surface temperature reduces.

In order to make a clear analysis of the temperature difference between the east and the west sides of the tent, the temperature changes on both sides of the tent are shown in Fig.9.

![Figure 9. The temperature difference between the east and the west sides of the tents.](image-url)

It is clear from Fig.9 that, before 12:00 the temperature difference curve is positive, namely the east wall temperature is higher, after 12:00 the temperature difference curve is negative, namely the west wall temperature is higher, indicating that the main factor affecting the surface temperature is the solar radiation. If the solar radiation is from the east, the east wall temperature is higher, if the sun radiation is from the west side, the west wall temperature is higher. The difference is the maximum temperature difference in the morning is about 6℃, while the afternoon temperature difference does not exceed...
4°C. The main reason is that after 14:00 the solar radiation reduced, the temperature rise of the west wall was little.

3.3. Web bulb global temperature

Web bulb global temperature is often referred to as the WBGT index, is a basic parameter for evaluation of the heat load of the workers, the unit is °C. Considering four factors of air temperature, wind speed, air humidity and thermal radiation, it is generally used to evaluate the meteorological conditions of high temperature workshop. The WBGT index can also be used to analyze the thermal environment of tent. During 7:30 - 17:30 on June 29, 2016, the WBGT index of the tent was recorded at the interval of an hour. Fig. 10 shows the WBGT trends inside different tents. In order to facilitate the analysis, Table 1 lists the WBGT index classification standard of high temperature working environment.

![Figure 10. Contrast of web bulb global temperature (WBGT).](image)

**Table 1.** WBGT index classification standard of high temperature working environment.

| Average energy metabolism level | WBGT index: °C |
|--------------------------------|----------------|
|                                | good | medium | poor | very poor |
| 0                              | ≤33  | ≤34    | ≤35  | >35       |
| 1                              | ≤30  | ≤31    | ≤32  | >32       |
| 2                              | ≤28  | ≤29    | ≤30  | >30       |
| 3                              | ≤26  | ≤27    | ≤28  | >28       |
| 4                              | ≤25  | ≤26    | ≤27  | >27       |

Generally speaking, the lighter a person’s physical work is, the lower his metabolic rate is. The metabolism is grade 0 at rest, grade 1 when a man is engaged in light physical labor in the tent such as meeting, learning, etc. The metabolic rate increases with the labor. From Table 1, if the staff are having a meeting or learning in the tent and belongs to grade 1 metabolism level, the environment can not be rated as good unless WBGT index is less than or equal to 30°C. Apparently, the temperature inside the tent without shading has exceeded the standard, and there are three times greater than 32°C (very poor). If the tent has a shading net, most of the solar radiation can be blocked, the WBGT index does not exceed 28°C. If the body is at grade 0, 1 or 2 metabolic level, the thermal environment can be evaluated as "good". So, setting up a shading net for a tent can reduce the WBGT index and provide better thermal environment for the people engaged in manual labor.

4. Conclusions

The indoor thermal environment of tents shaded by different density shading nets in summer was tested in this study. The results show that the shading net can block solar radiation well and improve the thermal environment of the tent. Because the heat of the tent mainly comes from solar radiation,
the cooling effect of the shading nets is very obvious. In the sunny days, the indoor temperature of the tent can be descended 8°C. The greater the knitting density of shading net, the greater the sun shading rate, the better improvement of thermal environment in the tent. It’s more obvious for the locations with strong solar radiation. The shading net had better cover all the surface of the tent, especially the east wall in the morning and the west wall in the afternoon.

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