Design and Research on New Green Nomadic Tents for Tibetan Nomads in Western China

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Abstract Tents, generally used as temporary shelters, have been neglected in architectural design for long. No designer cares about the living environment inside the tent because nobody is willing to choose it as a permanent residence. However, in Sichuan Province, China, many Tibetan herdsmen, whose business is still pasturing cattle, have to live a hard life for decades in traditional cow-hair-felt tents. They always suffer from kind of diseases because of the terrible environment inside the tent. To raise the living standard of Tibetan herdsmen, some new nomadic tents have been developed based on the concept of Integrated Design Process of green building design. This paper introduces the research achievement of new nomadic tents for Tibetan herdsmen. Factors involved in the design of the new tents for nomadic life such as thermal properties, supporting system, ventilation, and vernacular culture have been investigated systematically. Combination of different varies related to ventilation also have been tested to discover the most important one. An index named Ratio of Clerestory to Envelopment (RCE) has been suggested to evaluate the effect of natural ventilation inside the tent. Now the new nomadic tents have been accepted by Tibetan herdsmen as an ideal residence to their daily life.

Keywords New nomadic tents · Green building · Integrated design · Architectural design

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1 Introduction

In present western China, there are still a lot of ethnic minorities such as Tibetan, Kazakh, Mongolian, who are living a pastoral nomadic life and have no permanent shelters. Herdsmen rove around searching grazing land with the seasons. Taking Sichuan Province as an example, there are about 111,600 families (or 533,000 people) of Tibetan herdsmen living here, among which 99,000 families (or 473,000 people) do not have settled residence and most of them live in shabby shelters like kinds of tents, accounting for 88.6% of the total herdsmen [1].

Tibetan nomads have been living in traditional cow-hair-felt tent that is woven manually and supported by wooden pillars. The cow-hair-felt tent is the commonest shelter for nomads mainly because it suits nomadic life pretty well, owing to the facts that it is cheap and easy to assemble and disassemble. However, the living environment inside the cow-hair-felt tent is neither comfortable nor healthy simply because of its inherent defects such as the performance of bad heat insulation, water leaking, and bacterial contamination of cow-hair felt itself. It was reported that many residents living in the cow-hair-felt tent suffered from rheumatism, arthritis, etc. [2]. These existing problems show that cow-hair-felt tents cannot meet nomads' fundamental living requirement, let alone defend the elements whether from the viewpoint of personal health concern or from the scientific test results in the laboratory [3, 4]. In fact the cow-hair-felt tent, in its long history of evolution, has not changed much from its original design and its defects have been ignored. The possible reason for this condition is, perhaps, due to its temporary usage, low technology, and low-profit margin. Tents available on the market are mainly designed for short-term usage, such as disaster relief, outdoor camping, military training, etc. Actually, it is worth for designers developing new tents suitable for long-term nomadic life and this is an emergency in high altitude regions of western China. Most of present scientific researches related to tents came from the texture industry and were focused in material properties of tent cloth, different coatings of various tents [5–7]. Others involved the performance of water or oil resistance of tent cloth [8, 9]. Some researchers tried to improve thermal environment inside the tent by the experiment of artificial rainfall in recent years [10]. But none of these researches are based on thinking the tent as a building for everyday life. A program named "New tents for nomadic life" sponsored by local authorities aimed to develop new tents suitable for long nomadic life in high altitude regions of western China. The key factors of new nomadic tents development such as thermal physics performance, enveloping fabric materials, structural frames, and architectural culture have been researched fully.

2 Survey on Nomads in High Altitude Pasturing Region of West China

West Sichuan pasturing region located in Himalayas with mean altitude 3000 m high. The climate there is very atrocious for the heavy ultraviolet radiation, heavy storm of level 7–8, snow of 6–8 cm thick and hail frequently. The outdoor temperature in summer may be 0 °C in the morning but 30 °C in the noon. Therefore the material, construction, and design of new nomadic tents should be better in thermal performance than the common-use tents so that to improve the quality of indoor environment. Apart from the traditional tents made from cow-hair-felt, there are other kinds tents made from polyester material in West Sichuan pasturing region. Military camping tents with single pillar, framework tents for natural disaster relief, and leisure tents with multiple pillars for camping are probably the most popular ones under this category. Differed from the hand-made cow-hair-felt tent, these tents are commercial standard products. They are usually featured with fewer structural rods, less gross weight and better performances of waterproof and thermal insulation. However, they are not suitable for nomadic life in high altitude pasturing areas of western China for the following reasons:

(a) Fume Exhaust Deficiency: The air inside the tent may be severely polluted by the fume from the burning yak dung which is the commonest fuel [4]. But fume exhaustion is not considered in the design of commercial standard tents.
(b) Poor Heat Resistance: Without proper ventilation, the temperature inside the tent may rise harmfully high because of the intensive solar radiation in pasturing areas of high altitude. The greenhouse effect is almost inevitable owing to the poor air permeability caused by the thick, non-effective heat resistant surfacing material of the modern tents.
(c) Poor ventilation: Household activities, as well as some farming and meat processing works all happen in the confined space of nomadic tents, which is usually no bigger than 30 m^2, making it a concern over the issue of indoor air quality to some extent. Good ventilation is, therefore, necessary to exhaust stinky smell and keep the air fresh and healthy. Comparatively speaking, however, the cow-hair-felt tent is good at air permeability. Therefore many nomads in west Sichuan prefer the traditional cow-hair-felt tent regardless of its disadvantages.

Hence, the new tent, which is environmentally friendly and comfortable to live in, will not succeed until it can meet the requirements of long-term nomadic life and Tibetan nomads' custom. A questionnaire investigation involved 644 nomads in 6 counties of west Sichuan Province had been done to get further understanding on their requirements on the new nomadic tent.

A total number of 3570 suggestions have been collected. Their preferences on the functions of the tent are shown as following:

(a) Resistance against heavy wind, rain and snow;
(b) Excellent thermal insulation and heat preservation performance in winter;
(c) Good natural ventilation with little heat loss in summer;
(d) Easy to assemble and disassemble;
(e) Fireproofing. They also consider an ideal tent should be of waterproof, air-permeable and well-knitted. Furthermore, nomads in the pasturing region of relatively colder weather prefer a fabric of sandwich structure with an air layer or three layers with cotton pads to reserve heat indoor and those in mild weather area prefer monolayer tent cloth. As for the supporting structures, consist of frameworks or pillars, are required to be strong enough against heavy winds and easy to build as well.

Consequently, the new tent for long-term nomadic life in high altitude regions of west China is developed in terms of the above suggestions.

3 Discussion and Result on Three Key Technologies

3.1 Thermal Characteristics of Enveloping Fabrics and Their Housing Feasibility

To improve the thermal insulation property of the tent cloth is at top priority since the temperature fluctuating inside the tent depends almost solely on the enveloping fabric. 4 popular tent fabrics available on the market at present are PVC coating, PU coating, organo-silicone-treated and organo-fluoride-treated canvas. The research team systematically tested 7 indexes of the fabrics above and compared them with those of the cow-hair felt. The results indicate that the coefficient of thermal conductivity of the PVC coating relief tent cloth accounts to 0.0814 W/m K and other modern tents cloth account to 0.0470–0.0570 W/m K, which means the performance of heat insulation of different fabrics with different coatings are close to each other. Accounting to 0.034 W/m K, the coefficient of thermal conductivity of cow-hair felt showed the best heat insulation performance in all these tent cloths tested. Selection on surface coatings and the choices on layer combinations of different materials have to be taken into consideration in the design of new tents so to match the thermal insulation ability of the cow-hair felt if not better. Moreover, a thermal insulation performance test of typical fabrics is done in order to select the most proper fabric for the new tent. Figure 1 is the result of thermal insulation performance test of two different coating fabrics in hot days. It shows that the organo-fluoride-treated canvas (CVS) performs better on both the indoor temperature and surface temperature than that of tents enveloped by single layer PVC coating fabric (Note: CVS indicates organo-fluoride-treated canvas, PVC indicates fabrics covered by Polyvinylchloride). However, other experiments in winter nights

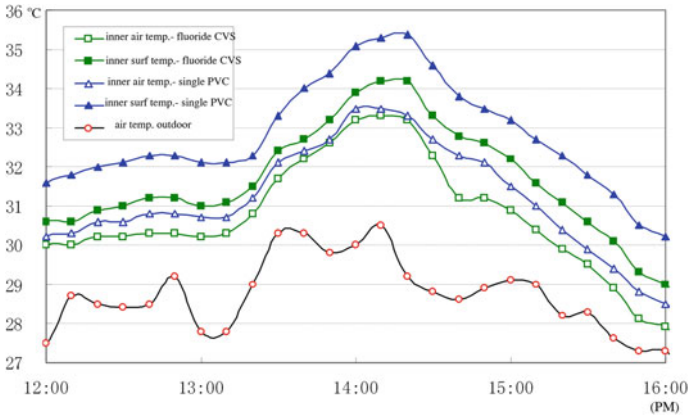

Fig. 1 Thermal insulation performance for different enveloping fabrics of the tent

show that both the indoor temperature and surface temperature of CVS tents are higher than that of tents enveloped by single-layer PVC-coating fabric.

With the analysis above, the organo-fluoride-treated canvas, with thermal conductivity of 0.042–0.055 W/m K, has been proven to be the most proper material available for the new nomadic tent. As for the performance of other enveloping materials, Wang Tao et al. reported unexpected results of indigenous improvement (shade cloth and double roofs which were invented by local people) on disaster relief tent in M8.0 Wenchuan earthquake region [11]. For the purpose of improving its thermal performance, the fabric was designed as multiple layers so as to compare its thermal performance of different materials combinations, for instance, monolayer fabric, double-layer fabric(outer and lining material) and three-layer fabric (outer, thermal insulation, lining material). The experimental result indicates that the air interlayer between the outer layer and lining in the three-layer fabric can improve the performance of thermal insulation largely. In addition, the fireproof lining material improved the fireproof performance with less cost as well. The air permeability and waterproof performance of the tent cloth jointly determine the indoor comfort—a serious health concern. Comparison of the air permeability and water resistance among different materials indicates that the cow-hair felt has an excellent air permeability but is poor in waterproof while the fabrics coated by PVC or PU have a good waterproof ability but a bad air permeability. The index that indicates the environmental sanitation is tested because the tent clothes have close contact with occupants in everyday life and the fabrics are easily contaminated by bacteria or fungi. The experimental result shows that the number of thermophilic aerobic bacteria on a cow-hair felt account for 5.5×10^5 (cfu/g) which is 220 times higher than that of chemical fabrics according to *Testing Method for Washed Feather and Down*—a state standard of China [12]. The test results also show that CVS and PVC perform much better than cow-hair felt in terms of weight, mechanical property, and endurance. Therefore, the sandwich-structured organo-fluoride-treated terylene waterproof canvas is selected as the enveloping

fabric of the new nomadic tent taking all factors above into consideration. The tents available on the market, among which black traditional cow-felt tent, green military tent and blue civil relief tent are the commonest, differ in shapes and colors. But a mass observation shows that nomads prefer white to other colors. Researchers also carried out tests on the impact of different colors on air temperature inside the tent to find out which color can provide a more comfortable thermal environment. The tents in tests were three blue civil relief tents covered by white, black, and blue canvases on the roof respectively. The testing period was during February. As shown in Fig. 1, the temperature in the tent-covered by white roof is much lower than that in the tent-covered by other color roofs. That means the greenhouse effect was obviously reduced in white tents. The same result has also been proved by similar experiments on the spot of M8.0 Wenchuan Earthquake [13].

3.2 *Supporting Frames and Anchoring System*

What the nomads concerned most in the mass observation is the new tents' resistance against heavy storm and snow. Thus, the goal of new tents' structural design is to resist the snow up to 8 cm in thickness and the forceful gale with a speed up to 20 m/s. What to do is to maximize the mechanical reliability of the supporting structure (including frameworks, guy ropes, anchor piles) of the new tent by means of software stimulation through the finite element analysis to ensure its safety even in the worst weather conditions. Based on the mechanic analysis result of *ANSYS*, structural components and support system are designed to bear the internal stress caused by storm and snow load. Figure 2 shows the diagram of internal stress worked out by *ANSYS*. Apart from ensuring the safety of tent structure under the worst work condition, the design also has to take the reduction of the amount of steel consumption into consideration so as to secure the best safety possible at the cost as low as possible. The structure of the nomadic tent differs from common buildings for the wind is the major load exerted on the tent and can tear or capsize it. The software *FLUENT* is used to simulate the side-blowing and lifting forces imposed on various tents by the gale. The standard load combination includes typical conditions of

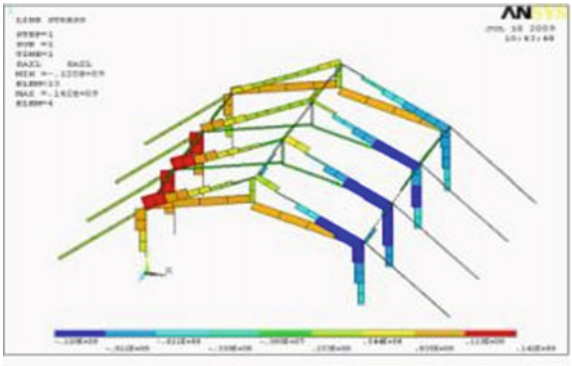

Fig. 2 Diagram of internal stress under wind load in ANSYS

gravity, snow weight of 8 cm in thickness and the side-blowing force from gale (perpendicular or parallel to side walls) with all the doors and windows are opened or closed relatively. The size of the tent model calculated in the software is 4.95 m × 4.15 m × 2.848 m, of which structure frameworks consist of 30 mm × 30 mm × 1.5 mm rectangular steel pipes (the width between each frame is 1.65 m) and guy ropes. Proper tent form and arrangement of wind-resist structure are worked out according to software simulation result. The guy ropes and anchor piles are the main tension components against the gale. Some experiments were designed to find whether the anchor pile could resist the gale. The tolerant pulling resistance of the anchor pile which was made from 40 mm × 40 mm angle steel is tested under the horizontal angle of pulling force at 90°, 75°, 60°, 45°, among which 90° to the earth is proven to be able to provide the maximum pulling resistance. The experiment on the spot of pasturing area showed that the pulling resistance of the anchor pile made of angle steel is larger than that of the rolled bar. For the anchor pile made of angle steel, the pulling resistance in the direction of "angle point close to tent" is 20% larger than that in the direction of "angle point far from tent". This is beyond nomads' traditional experience.

3.3 Ventilation and Mean Ratio of Cavity Area to Envelopment Area

In nomads' daily life, yak dung and core wood are the most used fuel, which is unlikely to change in a short time. The fume emitted from burning fuel will contaminate the indoor air. Fume exhaust and ventilation are obviously the two most important factors to be considered in nomadic tents design. Therefore, clerestory is necessary for the fume exhausting by means of natural ventilation in which the size and location of clerestories are the key factors. Tests according to *Textiles Determination of the Permeability of Fabrics to Air* show that the permeability index of cow-hair-felt accounts to 655 mm/s [14], which is 100 times larger than that of chemical fabrics(5–6 mm/s). Furthermore, the traditional cow-hair-felt tent is usually stitched by strips that are about 20–40 cm in width each. So the ventilation inside a cow-hair-felt tent is much better than that of modern fabric tents for its good permeability and the gaps between felt strips. Greenhouse effect is so obvious for synthetic fabric tents that the difference in temperature between indoor and outdoor may be 5–6 °C. Without clerestory, the temperature inside may be up to 45–50 °C and the inner surface temperature may be up to 55–60 °C in summer noon. In addition, side windows are necessary for day light and view.

Hence, an index named Ratio of Clerestory to Envelopment (RCE) or Ratio of Windows to Envelopment (RWE) is proposed to optimize the combination of clerestories (side windows). The index RCE and RWE describe the ratio of cavity area (clerestories, side windows, doors) to the total tent surface area. The quantification effect of natural ventilation could thus be demonstrated by these indexes approximately.

Figure 3 shows the curve of indoor temperature under different combination of RCE and RWE in this experiment (RCE indicates the area ratio of clerestories to envelopment of the tent; RWE indicates the area ratio of windows to envelopment of the tent). The relationship between the indoor temperature variation and the combination of different values of RCE or RWE is tested to find out their proper range. The experimental result, which was conducted under the condition that all side windows are closed, indicates that heat-shielding capacity and fume exhaust would be improved evidently when the RCE was set between 0.008 and 0.03 or RWE between 0.05 and 0.15 and the effect of natural ventilation would be the best when the RCE was set between 0.01 and 0.02 or RWE was 0.10.

4 Representation of Tibet Architectural Culture in Nomadic Tents Design

The time-honored cow-hair-felt tent originated from Tibetans' nomadic lifestyle long time ago. As an integral part of Tibetan culture, the tent, in traditional form, is endowed with ethnic and religious features. It is not only a matter of respect, but also a matter of acceptability and marketability of the tent for designers to take these features into consideration and make sure they are shown on the new tent properly. It was pointed out that the gorgeous, pure and simple Tibetan architectures expressed the tinge of plateau and represented a unique aesthetic taste on colors [15]. Zashi Daje, a typical architectural decoration pattern in Tibet, was the eight symbols of benediction related to Buddha or the celestial power of Buddha [16]. Endowed with some mysterious profundity, this pattern is a very common and popular painting theme in Tibetan frescos, bronze-carvings, and woodcarvings. Being a "soft building", the new nomadic tent should be designed massive and stocky in shape so to represent the figure of soil and stone construction on the Tibetan plateau. Moreover, due to the unique color and decorative pattern of Tibetan architectural culture, the body of the new nomadic tent should be white but trimmed with blue or black edges. Auspicious cloud scrolls are painted as ornaments in corners. In the large blank area of the tent, the eight mascots—lotuses,

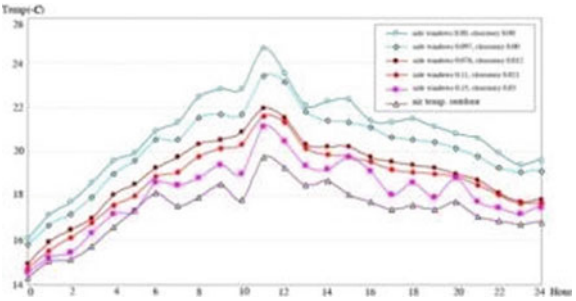

Fig. 3 Indoor temperature variation inside closed tent with different RCE or RWE

Fig. 4 Appearance of new tents decorated by Tibet cultural symbols

gold annuluses, auspicious knots, and others are painted as decorations, making a sharp contrast between the patterns and the white background and at the same time profiling the shape of the tent. Figure 4 is a picture of some new nomadic tents decorated by Tibetan culture symbols.

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