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Improved Infantry Winter Shelter Project

Randall J. Osczevski

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Author

Randall J. Osczevski

Approved by

Pang Shek

Head, Operational Medicine Section

Approved for release by

Kathy Sutton

Chair, Document Review and Library Committee

Abstract

Much of the frost and ice that form on the inside of the tent comes from water produced by the combustion of naphtha fuel in the heating, lighting and cooking systems. Frost also accumulates in sleeping bags when used in extreme cold and cannot be removed or dried with the present shelter heating system. Modifications to the group shelter are recommended to increase warmth and minimize problems with closure systems. These include an adjustable liner, insulation on the door zipper and more radical changes to the tent opening to eliminate zippers entirely. Other shelter concepts, including individual and modular shelters are reviewed as possible replacements for the group shelter. The major recommendation to improve moisture management in sleeping bags and tents is a small forced-air tent furnace. As envisioned, it would be based on the existing stove, but would generate its own power as well as DC electrical power to run a lighting system and to recharge batteries.

Résumé

Une grande quantité du gel et de la glace qui se forment à l'intérieur des tentes provient de l'eau produite par la combustion du naphte dans les systèmes de chauffage, d'éclairage et de cuisson. Le gel s'accumule aussi dans les sacs de couchage utilisés par temps de très grand froid et le système de chauffage d'abri actuel ne peut ni l'éliminer ni le sécher. On recommande de modifier l'abri de groupe pour accroître la chaleur et minimiser les problèmes liés aux systèmes de fermeture. À citer parmi les recommandations sont : doublure ajustable, isolement de la fermeture à glissière de la porte et d'autres changements plus fondamentaux à apporter à l'ouverture de la tente pour éliminer complètement la fermeture à glissière. Le rapport traite de la gestion de l'humidité dans les tentes et les sacs de couchage et présente brièvement des recommandations pour changer le système de chauffage/d'éclairage afin d'améliorer la gestion de l'humidité. L'autre abri des concepts, y compris des abris individus et modulaires sont passés en revue comme possibles remplacements pour l'abri de groupe. La recommandation majeure vise un four à air forcé pour tente qui séchera celle-ci et les gros articles comme les sacs de couchage. Il serait, probablement, basé sur le poêle existant mais générant son propre énergie et un CC pour faire fonctionner un système d'éclairage et recharger des batteries.

Executive summary

The weight of both the sleeping bag and the tent increase when used in extremely cold weather. Frost and ice form on the inside of the tent from the occupants' breathing and from water produced by the combustion of naphtha fuel burned by the heating, lighting and cooking systems. Frost and ice render the door closure zippers inoperative in extreme cold. The sleeping bag is the largest item of personal equipment carried by a soldier. When used in the cold, water accumulates in the insulation, making the bag heavier and colder to sleep in. The best down sleeping bags, which have the lightest weight and the most insulation, are the most seriously affected by ice accumulation. While CF bags seem to be less dramatically affected, even the small amount of moisture condensed during a short period of use can have a significant effect on soldier comfort. Possible modifications to the 5 and 10 person tent to increase concealment, internal temperatures and to solve the problem of door closure icing are discussed. The current tent heating system, a two-burner stove and a lantern, is a major source of condensable water vapour in the tent. It also does not lend itself to drying large items such as sleeping bags, or the tent itself. Changes are recommended, including venting combustion products and an add-on forced-air tent furnace to heat and dry the tent and other large items such as sleeping bags. The proposed tent furnace, which would be based on the existing two burner stove, might use a Stirling engine and/or thermoelectric modules to generate its own power as well as DC electricity to run a robust, light weight LED based lighting system and to recharge batteries for the many electronic items that will be used by tomorrow's warriors.

Osczevski, R. J. 2005. Improved Infantry Winter Shelter Project TR 2005-132. DRDC Toronto.

Sommaire

Le poids du sac de couchage et de la tente utilisés par temps de très grand froid augmente. Gel et glace se forment à l'intérieur de la tente, résultant de la respiration des occupants et de l'eau produite par la combustion du naphte consumé par les systèmes de chauffage, d'éclairage et de cuisson. Le gel et la glace bloquent les fermetures à glissière de la porte par temps de froid extrême. Le sac de couchage est l'article le plus grand qu'un soldat transporte. Par temps froid, l'eau s'accumule dans l'isolation, rendant le sac plus lourd et trop froid pour qu'on puisse dormir à l'intérieur. Les meilleurs sacs de couchage isolés duvet, qui pèsent le moins et sont les mieux isolés, sont ceux qui présentent les plus graves problèmes d'accumulation de glace. Les sacs de couchage des FC sont apparemment beaucoup moins touchés par ce problème, mais quand même la moindre condensation d'humidité pendant une brève utilisation peut mettre le soldat considérablement mal à l'aise. Ce rapport traite de modifications possibles à la tente de 5 à 10 personnes pour rendre celle-ci moins visible et plus chaude à l'intérieur et pour résoudre le problème de gel de la de fermeture de la porte. Actuellement, le système de chauffage des tentes, composé d'un poêle à deux brûleurs et d'une lanterne, est une source majeure de vapeur d'eau condensable dans la tente. Il ne se prête pas non plus au séchage de grands articles comme les sacs de couchage ou la tente elle-même. Des changements sont recommandés, à savoir des produits de combustion relatifs à la ventilation et un générateur d'air pulsé d'appoint pour tente qui chauffera et séchera la tente et les grands articles comme les sacs de couchage. Le four à air forcé pour tente, qui serait basé sur le poêle à deux brûleurs actuel, pourrait utiliser un moteur Stirling et/ou des modules thermoélectriques pour générer son propre énergie et un courant continu pour faire fonctionner un robuste système d'éclairage léger à diode électroluminescente et recharger des batteries pour les nombreux articles électroniques qui seront utilisés par les combattants de demain.

Osczevski, R. J. 2005. Improved Infantry Winter Shelter Project TR 2005-132. DRDC Toronto.

Table of Contents

List of figures

Introduction

The weight and bulk of both the sleeping bag and the tent increase when used in extremely cold weather. The 10-man arctic tent, with a dry weight of 37 kg (81 lbs), is the bulkiest, heaviest item used by an infantry section. Each day, its weight and packed volume grow a little bigger so that eventually it outgrows the toboggan used to transport it. Frost and ice form on the inside of the tent from the occupants' breathing and from water produced by the combustion of naphtha fuel burned by the heating, lighting and cooking systems. A 1997 survey of the ten-person tent group system observed:

"Overall tent system weight was considered as too heavy. This problem is exacerbated following use in the field as the tent system becomes heavier due to water, snow, and ice retention."

"Following outdoor use in the cold/snow folding and packing the tent on the toboggan was rated as an unacceptable and difficult task due primarily to the condition of the shell and liner. The materials used were reported to become stiff in the cold and the presence of ice makes folding and stowing the items in a confined space difficult. The resulting increased volume of the folded tent also contributes to the difficulties noted during the task of lashing the toboggan, as the outer bag of the toboggan does not easily accommodate the increased bulk." (Gaughan and Kumagai 1998).

Another significant problem is the tent door closure. It takes two hands to open and to close the two zippers, which is awkward and slow, and they malfunction in extreme conditions. In fact, the door is so troublesome that soldiers sometimes just crawl under it rather than use the zippers. The door closure system was rated unacceptable by 70% of responders in the 1997 survey:

"The zippers tend to freeze and become difficult to operate. Due to the frequent use of the doors and zippers, they often become unserviceable or very difficult to operate" (Gaughan and Kumagai 1998).

The sleeping bag is the largest item of personal equipment carried by a soldier. When used in the cold, each night the mass of the sleeping bag increases as water accumulates in the insulation, making it colder to sleep in. The best down sleeping bags, which have the lightest weight and the most insulation, are the most seriously affected by water accumulation. With continued use over a few weeks, the down can become concentrated into fist-sized lumps of fibre-reinforced ice (Weber 1990; Osczevski 2003), having little value as insulation. More commonly, periods of use are shorter and the degradation in warmth is less spectacular, but theoretically even the small amount of moisture condensed during the first night of use can have a significant negative effect on soldier comfort and on the duration of restful sleep.

There is no heater designed specifically for CF infantry section tents. Troops use the two-burner stove (Fig. 1), which was designed for cooking rations and heating water, and the naphtha-fuelled lantern as heat sources. This "system" is part of the moisture management problem as it is a major source of the water that accumulates in the tent. It also does not lend itself to the process of drying large items such as sleeping bags, or indeed, the tent itself.

Changes to the way tents are heated, such as adding fan-forced ventilation and venting exhaust products, might overcome many of the problems noted above.

Figure 1 Two-burner stove used for cooking and for heating a 10-person arctic tent

Group shelter

The fact that the in-service, tried-and-true tent design (Fig. 2) has been around in much the same form since the 1940's (DND 1944), suggests that despite the readily apparent shortcomings of the current version, a group tent is a good fit to military operational requirements and to the needs of small groups in highly stressful conditions.

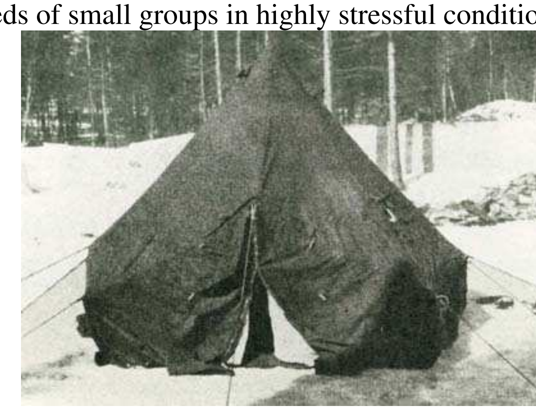

Figure 2 An early 6-man version of the arctic tent ca. 1942

The vertical wall section of the in-service tents must increase the effective sail area of the tent considerably. In wind, there is a rotational flow of air that starts on the upwind side of the tent as in Fig. 3. The resulting turbulence shakes the tent and reduces the thermal insulation of the air space formed by the liner. The rotary flow of wind around the base of the tent can also sweep the snow off the snow flaps as shown in Fig. 3, eventually causing the tent to fill with wind, which puts huge stresses on the tent fabric and anchors.

Flow over and around a cone that touches the ground is likely to be much less turbulent. The insulation of air spaces between the inner and outer walls of a conical tent might therefore be higher because they will be more stable. There is also relatively little lift generated when the air flows around and over a conical shape.

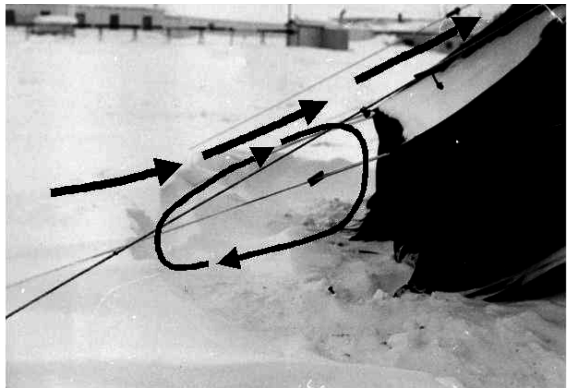

Figure 3 Windward eddy scoops snow off of the flaps.

The data sheet for the in-service “10-man” tent claims that it has an area of 21 m^2, but that is its footprint, not its floor area. The footprint includes the area of the snow flaps, which are outside the tent. The interior floor space is only 16.3 m^2 (175 sq. ft.), which explains why it is so difficult to put 10 men in it.

A commercially available tent (Fig. 4), nominally for 8 occupants, weighs only 5.1 kg (11.3 lbs), complete with the liner, pegs and centre pole. It has an elliptical footprint with an interior floor space of 19.7 m^2 (212 sq. ft.) When packed, this tent is smaller than a sleeping bag in its valise. Although it has a significantly larger floor area, the useful space for sleeping is reduced because it has no vertical wall section. However, the perimeter area of the floor could be used for storage of backpacks, etc. The door zippers come down to the ground and can be difficult to reach from the inside.

Figure 4 Eight person tent from Kifaru International.

The fabric of this tent is very light, possibly not strong enough to withstand the rigours of normal military use. Because such light nylon or polyester fabrics have a low mass per unit area, they also have a correspondingly low heat capacity. This means they heat up quickly and can almost instantly melt when touched by a flame or a burning ember. However, if the fabric weight of the tent in Fig. 4 were doubled, or even tripled, it would still weigh much less than the current 10-person arctic tent. This suggests that it might not be too difficult to produce a section-sized tent with a much smaller weight and bulk than the present one.

The fit of the tent lining is critical to the insulation it adds to the tent (Osczevski 2004). When a few small slits were made in the liner 5-person tent so that it could be optimally fitted to the attachment points on the tent, the tent thermal resistance increased significantly. With the normal 6 kW heat input, its internal temperature would be 15 ºC warmer after the adjustment. This is the difference between the temperature inside a refrigerator and a comfortable room temperature.

Multiple small tents

With modern materials and designs it might be possible to provide five 2-person tents to replace the group shelter without incurring a penalty in terms of mass and packed volume. However, in the extreme conditions in which it would sometimes be used, the effect of isolating two-man groups on overall section morale might not be positive (M. Thompson, personal communication 2004). Moreover, there will still be a requirement for a heated shelter when sentries are posted. The hazards of open flame stoves are even greater in smaller tents. Small commercial tents, even those designed for expeditions, must be extensively modified to bring them up to military operational requirements (Whitehead 2003).

Modular tents

An alternative that has been suggested previously is to produce a modular system in which sleeping tents and a central tent for group activities such as cooking and eating are connected in something like a snowflake pattern. A modular complex, such as that in Fig. 5, could probably not be built by a small part of the section in less than the 5 to 10 minutes it takes a trained crew to set up a ten-man tent (Gaughan 1998).

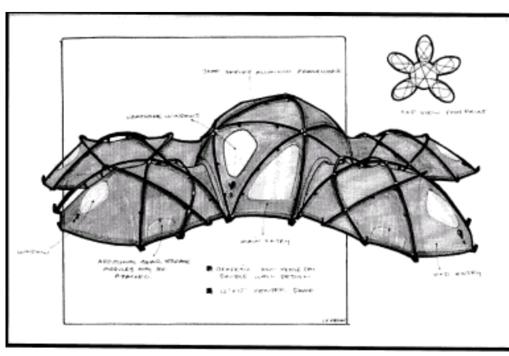

Figure 5 Hub and spoke tent concept drawing

A modular shelter system is commercially available from Terra-Nova in the U.K. Several 2-person "Stoer" tents can be docked with a central "Forum" tent by means of zippered ports in its walls (Fig. 6).

Figure 6 Modular tent from Terra Nova (UK).

Some problems with this concept can be identified. Foremost, there is the difficulty of heating such a complex of tents. The total surface area of the hub and spokes will be much greater than that of a single large group tent. As the heat loss is proportional to the surface area, other things being equal, comfortable interior temperatures will only be reached by burning fuel at a higher rate. This means more fuel on the toboggan and more stoves or new stoves with higher heating rates. Hopefully, new stoves would be safer to operate than the two-burner camp stoves that have been used for several decades (Pang 1974).

A "flake" design would not solve the problem of water accumulation in the tent. Large radial temperature differences are likely, with the "bedrooms" being much colder than the "kitchen" where the heat is produced. Much of the humidity in the air would then condense in the far-flung areas, producing dampness and frost in the sleeping tents. The same thing happens in the present group tent, where frost accumulates between the walls. A central tent furnace would be useful in such a complex if it could provide dry, heated air by means of a distribution system to the other "rooms" or directly to occupied sleeping bags.

Closures used to dock the tents will have to work easily in the cold and when covered with ice. Zippers and most other fasteners do not have a good record in this respect in heated tents. Also, zippered doors on a tensioned fabric tent do not operate silently. On a still morning the chorus of zippers that accompanies the rising of a group sheltered in several small tensioned tents can probably be heard from a large distance (Osczevski 1991). A reliable, silently opening tent door is a tactical necessity.

Attempts to heat the small tents with small naphtha-fuelled stoves would be fraught with the dangers of fire and carbon monoxide, particular if the tents have floors, as integral floors seriously limit ventilation when the tent is buttoned up tight. Because 2-person sleeping tents are low and have little room for heating equipment, they would probably not normally be heated, except passively by being docked to the central hub. The users would have a choice between docking the small tents and risk them becoming condensation zones, or setting the small tents up at some distance from the central hub and not heating them.

In winter, at least the central tent would have to be heated throughout the night so that sentries can be posted and rotated. Some section personnel might sleep in the heated central tent while others would have to sleep in the cold. This might be bad for morale and unit cohesion in harsh conditions. If everyone in the section could be housed in one or more central hub tents, the side tents might not be used at all and the hub might then evolve back into a group tent.

If all the tents of the complex are the same and all are heated, some of the social difficulties noted above might not occur. Consider three identical tents that can be pitched separately or connected, each capable of housing 4 to 5 soldiers. These may be, for example, three tunnel tents similar to the one in Fig. 7, each with a door in each end, connected end to end in a line or some other geometry. Tunnel tents of a similar design (Cain, 1985) have been used by DRDC personnel on several extended winter trials (Osczevski, 1989). This shelter complex would still have a large surface area for heat transfer, but the occupants would retain the social benefits of a group tent. As each module is large enough to be heated safely, condensation should not be as big a problem as in a hub and spoke complex and heat distribution should be improved. The advantage of this system over the current group tent is that each squad of 4 or 5 soldiers would have the ability to be independently mobile. Three squad toboggans might be required, but they needn't be as large as the toboggan currently in use. Redesign of the toboggan should take into account the dimensions of the tent support poles and the heating system.

Figure 7 Experimental insulated tunnel tent

Sleeping Bags

The ice that forms in the sleeping bag starts out as fluffy frost, but it melts when the bag is in a heated tent, wetting the insulating material. During the day when the sleeping bag is packed and placed outside of a heated shelter, the water in the compressed insulation freezes again. The next time the bag is used, this ice holds part or all of the insulation in its compressed state until body heat melts it and it can loft fully (Osczevski 2003). After many nights, this process can take hours, stealing body heat. With continued use, down can become concentrated into fist-sized lumps of fibre-reinforced ice (Weber 1990). Because the insulation is compromised, body heat may no longer be sufficient to thaw the ice.

One cannot dry a sleeping bag by leaving it unpacked and unoccupied on the cold floor of a heated tent. Instead, a thermal and moisture gradient will be set up that drives water vapour from the top of the bag, where it had condensed the evening before, back to the cooler inner regions of the bag. This will make the bag colder to use the next time, as that water will evaporate again and diffuse back to the outer bag taking body heat with it (Osczevski 1989). Even in the arctic summer, a sleeping bag will not dry if left on the floor of a tent. Instead, the sleeping bag will insulate the floor below it so that its temperature drops to something close to the temperature of the underlying permafrost. Water vapour in the tent air will then diffuse through the bag and condense wherever it is colder than the dew point. This can make the bottom of the bag sopping-wet, so that it seems as if water has come up through the tent floor (Osczevski 1991).

If the frost in a sleeping bag stays frozen, the insulating filling will not be subject to ice-cemented clumping. Ideally, stoves should not be lit in the morning until the sleeping bags have been packed and placed outside and the frost on the tent has been brushed off. However the packed sleeping bags are needed for seating, for the lower reaches of even a heated ten-person tent can be uncomfortably cold. There are other drawbacks to this rather Spartan solution to the problem of moisture accumulation, which was successfully pioneered by polar adventurer Richard Weber (Weber et al. 1990). Not the least of these is that the issued sleeping bags are not always warm enough in extreme cold without supplemental space heating. While trekking over the Arctic Ocean, Weber noted that although his sleeping bag continued to gain weight each night, the collected frost did not harm its insulating value. In fact, Weber suspected that the frost might have actually made the bag warmer (personal communication, 1992).

Ice ball formation and insulation clumping that seriously affects the use of high lofting down insulation in commercial sleeping bags has not been reported with the down and feather mixture in CF arctic sleeping bags. Possibly, this is because the dynamics of a peacetime exercise allow the tent to be at least marginally heated all night.

Sleeping bags insulated with synthetic fibres also gain weight over time. One polar traveler noted that after 20 nights his thick synthetic sleeping bag had gained about 9 kg (20 lbs) and had become very cold to sleep in (Steger 1988).

An internal vapour barrier between the warm occupant and the insulation should prevent condensation in the insulation. Unfortunately, few truly impermeable materials remain flexible when subjected to arctic cold. Even if the barrier remains flexible and doesn't crack and leak water vapour, the barrier will inevitably be cooler than the skin temperature and will therefore become wet with condensation in some conditions. Because water vapour cannot diffuse out the space next to the body, the relative humidity in the air inside the bag will be very high. The humidity and dampness can be very uncomfortable. Evaporative heat loss from the skin is sometimes necessary for thermal comfort in a sleeping bag, even in very cold conditions (Osczevski 2003).

A vapour barrier farther away from the body might be preferable from a thermal comfort and hygiene standpoint than one next to the skin. By placing a vapour barrier between the inner and outer bags, at least the insulation in the outer bag would be protected from water vapour coming from the skin of the occupant. A spacer placed between the vapour barrier and the outer cover of the inner bag would create a cold trap to collect the condensation. It might consist of a very open textile net or small pieces of closed-cell foam glued to the inside of the vapour barrier to create an air space. Much of the water vapour that leaves the skin and manages to diffuse through the warm inner bag would then condense on the vapour barrier and collect in the cold trap. If the inner bag had a microporous waterproof vapour permeable outer cover, which would incidentally allow it to be used outside in wet cold, it would also be protected from any water condensed in the cold trap. Once frozen, this ice could be removed every few days by separating the bags.

Unfortunately, materials and coatings that are impermeable to water vapour are also impermeable to oxygen (O_2) and carbon dioxide (CO_2). Wherever a vapour barrier is situated, it will keep fresh air from getting into the sleeping bag and stale air from getting out. Sleeping with one's head inside the sleeping bag is an unconscious response to facial cooling. It is not recommended but it frequently occurs. With a vapour barrier, the sleeper might be repeatedly awakened by the increasing level of CO_2 in the air in the sleeping bag, making it difficult to get restful sleep in intense cold.

A small personal heater, such as the Heatpac™ from STK (Norway) might be used on a weekly basis to heat the interior of the sleeping bag to drive water from the insulation. It weighs only 500 g, runs on a D-cell, burns solid fuel, and produces 150 to 300 W of heat for several hours.

Heating System

The standard two-burner stoves that have been used for many years to heat the 5 and 10 person tents leave something to be desired from the standpoint of safety. Operation of naphtha-fuelled stoves is sometimes difficult, especially when the stove and/or the fuel are extremely cold (Pang 1974). Even plunging a burning match into a pool of cold naphtha will often not set the fuel ablaze because its vapour pressure is so low. If the generator of the stove is not seated correctly, as sometimes occurs, cold fuel can leak unnoticed and collect in the bottom of an operating stove. Fuel is stored outside, so at stove start up, it is initially at outside temperature. As the stove heats up, the vapour pressure of the spilled fuel increases. When it becomes warm enough, the pool ignites. The resulting fire can be dangerous as well as spectacular. It is not unusual to have stoves return from cold weather exercises blackened by accidental fires and dented by being booted out of the tent while engulfed in metre-high flames.

The stove is not vented to the outside, so the occupants breathe whatever is in its fumes. The orange colour in the flame (Fig. 8) might be emissions from hot soot or partially burned hydrocarbons. These combustion products can irritate the eyes and lungs; moreover, any burner flame that is cooled by contacting a cold pot can also produce deadly carbon monoxide (CO) (Osczevski 1977; 1979). Because it cools the flame, a small amount of water in the fuel can also result in an orange flame and incomplete fuel combustion.

Figure 8 Main burner of the stove in Fig. 1. Note the orange colour of the flame.

Even when operating perfectly and burning with a flame with no orange colour, pressure stoves produce two unwanted combustion products: CO_2 and water. They also consume oxygen from the air in the tent. The formula for the perfect combustion of a general hydrocarbon fuel is:

$$C_n H_{2(n+1)} + \left[\frac{3n+1}{2}\right] O_2 \Leftrightarrow nCO2 + (n+1)H_2O \qquad [1]$$

For each mole of fuel burned, n moles of CO_2 and (n+1) moles of water (H_2O) are produced, where n is the number of carbon (C) atoms in a molecule of the hydrocarbon fuel. Approximating naphtha as octane (n=8), each litre of fuel would contain 6.1 moles of octane. When burned, (8+1=9) times as many moles of water are produced (55 moles). This is equivalent to about 0.8 litres of condensed water for each litre of fuel burned.

As the two-burner stove burns naphtha at a rate of about 0.5 litres/h, it produces water at a rate of approximately 0.4 litres/h (condensed). The water starts out as hot vapour but it cools rapidly in the cold air of the tent. It can condense to a super-cooled fog that freezes on contact with cold objects to form rime (Fig. 9), or sublimate on cold surfaces as hoar frost crystals.

Ventilation is not assured by opening the vents at the peak of the tent. A heated tent is like a fireplace chimney; it must have openings at both ends to draw. A tent needs vents at the top and at the base to ensure a free flow of ventilating air. Except for the volume change caused by burning the fuel, no warm air will go out the vents at the peak if fresh air cannot easily flow in at the base of the tent to replace it. The coated fabric floors of many commercial tents greatly restrict ventilation by preventing the inflow of replacement air. Billowing of the tent floor is a sure sign of restricted ventilation.

Figure 9 Powdery rime coats the inside of the grey liner of an arctic tent in extreme cold.

The air coming in at the base is cold and should ideally be ducted directly to the heater to avoid chilling the occupants. The stove should be vented to the outside to remove combustion products, including water vapour, however, some heat will be lost up the stack.

O_2 is consumed while the stove is burning. If O_2 is consumed faster than it can be replaced by ventilation or by diffusion through the tent walls, its concentration will drop in the shelter. Low oxygen might not be noticed as it has only a small effect on respiration until the partial pressure of O_2 is less than half of what it is in normal air. This would be equivalent to the partial pressure of oxygen at an altitude of 5,200m (17,000 ft.) (Lambertson 1974). The effects of such low oxygen pressure on humans include significant lapses in short-term memory, diminished performance on mental tasks, and deterioration of sensory performance (Fulco 1986).

However, combustion in a shelter also increases the level of CO_2, a gas that is more easily sensed. When CO_2 exceeds a concentration of about 4%, it causes an increase in respiration rate that most people easily notice. It can be difficult to sleep in a tent that is not permeable enough or is insufficiently ventilated. Also, stoves may not burn as cleanly when oxygen is less available, so that equation 1 is no longer valid. Partially burned hydrocarbons, soot and deadly CO might then become significant combustion products. Unless the tent is forcefully ventilated, tent fabrics should be uncoated and permeable to oxygen, for natural convection cannot be relied upon to produce ventilation. Note that some fabrics that are said to be waterproof but “breathable” with respect to water vapour are ***not*** permeable either to oxygen or carbon dioxide (Osczevski 1995).

Forced air heating of ten-man tents was successfully attempted on a winter exercise in 1981 (Osczevski and Cain 1982). Hot air was ducted from the heaters of M113 armoured personnel carriers into the tents through several metres of a 10 cm diameter silicone rubber vehicle heating vent. Air temperatures measured in one of the tents were almost uniform at +20 ºC at heights above one metre. Carbon monoxide was barely detectable -- lower than had been measured when liquid fuelled pressure stoves were used for cooking and heating. With forced air heating and ventilation, the temperature was a comfortable +10 ºC at the centre of the tent 10 cm (4 in) above the floor. At the time, the temperature outside the tent was –37 ºC, with a wind of 40 km/h. Unfortunately, the heat output and airflow rate of the diesel fuelled Perfection heater in the M113 are not known. Modern diesel fuelled vehicle heaters produce 10 kW to 20 kW (30,000 to 60,000 BTU/h) of heat. Ten kilowatts is sufficient to raise the temperature inside an M113 to +15 ºC when the ambient temperature is –40 ºC (Cain 1984). Although the vehicle heaters may have been more powerful than the standard stove/lantern combination, not all of their heat output went into warming the tent. Some heat was used to warm the interior of the vehicle and a significant amount was probably lost from the several metres of uninsulated vent hose between the vehicle and the tent.

Had standard two-burner naphtha fuelled stoves and lanterns been used to heat the tents, the temperature at 10 cm would have been about –17 ºC (Osczevski 1977) and there would have been a large vertical gradient of temperature, with the highest temperatures occurring in the peak of the tent.

The flow of heated air from the vehicle heaters not only heated the tent but also mixed the air inside it and so improved the temperature distribution by bringing more heat down to where the occupants were. In so doing, it probably also reduced the hot spot at the peak of tent that shows up so well on thermal infrared imaging systems. Blowing heated outside air into the tent reduced the dew point in the tent and minimized condensation and frost formation. The tents that used the vehicle heaters remained dry and flexible and easy to pack into a minimum volume. The atmosphere inside the tent was excellent for drying clothing and for drying the tent itself. The occupants were warm and slept comfortably. An added benefit of the dry heat was that the tent door zippers did not ice up and continued to function perfectly, despite the extremely cold conditions.

With the greater heat at floor level, it wasn't necessary to stand to get warm. Each occupant could lie on top of their sleeping bag after entering the tent and could nap when the situation allowed, still dressed and ready to go at moment's notice. The extra height of the tent was not needed, except to hang up small items of wet clothing. If we were to reduce the height in future designs, concealment would be enhanced, fuel requirements reduced and thermal comfort would be increased as more heat would be concentrated in the lower levels.

Infantry units will often be without vehicles that might act as sources of heat or electrical power for forced air heating. The same benefits might be obtained from a small tent furnace coupled with a portable electrical generator, or a tent furnace that generates its own mechanical or electrical power. This could be used to dry the tent or the sleeping bags by ducting hot air into their interior. It could also be used to provide heat to each person directly instead of heating the whole tent, helping to conceal it from infrared (IR) sensors. By pressurizing the tent slightly, unintended inward air leaks and draughts would be prevented. Intake air could be filtered to afford some degree of chemical, biological or radiological protection. The increase in toboggan load caused by having a heavier stove would be partially or totally offset by the reduction in accumulated moisture in the tent and sleeping bags.

There is at least one fan-forced external heater for tents on the commercial market (Fig. 10). It burns propane, which rules it out for extreme cold weather, as the gas pressure in a propane bottle decreases substantially in low temperatures. The heat exchanger, burners, fan and ducts have a mass of 3 kg (6.6 lbs). It has a rated heat output of 6 kW (20,000 BTU/h), which is about that of the Coleman two burner stove and lantern. Its 12 V DC fan delivers about 50 litres/sec (~100 cfm) and draws 3 to 4 A of current.

Figure 10 Fan-forced tent furnace (Hot Vent by Zodi)

Honda makes a "hand held" gasoline-powered motor generator (Fig. 11) with a rated output of 900 W, which includes a 12 V DC supply for charging batteries. At ¼ of the rated load, which would be more than enough power to run a tent furnace fan, the generator could run for 8 hours without refuelling. It weighs 13 kg (29 lbs), which is light for a power supply of this capacity. According to Honda, at a distance of 7 m (22 feet), the engine noise is no louder than normal conversation.

Figure 11 Ultra quiet hand-held generator (Honda)

A disadvantage of a motor generator is that it must be used outside the tent because of the hazardous exhaust fumes, so the heat from the engine is lost. Extra fuel must therefore be carried for it. Efficiency would be improved if the engine were surrounding by a shroud through which air could be forced by a fan. The engine would then be cooled and a flow of heated air would be available for a nearby shelter. The engine of a snowmobile was once used in this manner (Osczevski 1995). Care would need to be taken to avoid drawing in the engine exhaust of course, so CO in the air stream might have to be monitored.

The relatively abundant AC power a generator produces might be directly used to heat individuals in insulated bags, increasing heating efficiency, minimizing the requirement for space heating and reducing the IR signature of the tent. A single generator might be used to heat sleeping bags in more than one tent, or in expedient shelters.

Electrical power to charge batteries and power lights and mechanical energy to run a fan could be generated from the heat of the tent furnace itself. A Stirling engine is one possible way to use at temperature difference to generate mechanical and electrical energy. These engines differ from an internal combustion engine in that its energy comes from an external source, as does a steam engine. Instead of boiling water, the externally generated heat that powers a Stirling engine raises the temperature of air in a cylinder so that it expands and pushes a piston. They are consequently comparatively quiet.

A Canadian-made 95 litres/s fan (200 cfm) driven by a small Stirling engine is commercially available (Fig 12). It is designed to run on the heat from a wood stove. This sturdy device weighs 7 kg (15 lbs), and is not subject to failure from overheating. It could be made much lighter, as most of its weight is used for fan stability when it is running, for it sits on the wood stove and is not attached to it.

Stirling engine-based electrical generators are available for off-grid, remote and marine power applications. A DC model from Whisper Tech (New Zealand) operated flawlessly at a remote observatory at the South Pole for four months. It produced 800 W of DC power at 24 V and 6 kW (20,000 BTU/h) of useful heat. The generator was not designed to be portable, however.

Figure 12 Sterling engine fan (Meal Time Stoves)

Thermoelectric generators are also attractive as they are silent and have no moving parts. These are solid-state devices that convert a small part of a flow of heat to DC current. However, overheating can easily ruin thermoelectric generators because the individual elements are thermally and electrically connected by solder, which melts if the temperature is too high. Clearly, the cold side heat exchanger design and operation are crucial to preventing overheating.

The pot sitting on the camp stove in Fig. 13 is not only used to melt snow and boil water. It uses a thermoelectric generator produce 8 W of electrical power at 12 V DC. This power may be used to recharge batteries for electronic devices that might be carried by soldiers. The water in the pot keeps the device from overheating. Because the efficiency of conversion is low, about 4% in commercial systems, to generate significant amounts of power, kilowatts of heat must pass through the array of thermo-elements.

Figure 13. A small thermoelectric battery charger that runs on the heat from a camp stove (Kryotherm).

Near the other end of the man-portable range is a new forced convective heater developed for the US Army. It has an integral thermoelectric generator that provides electricity to power the internal blower. The heater produces 140 litres/s (300 cfm) of hot air, 10 kW (30,000 BTU/h) of heat, but it weighs in at 34 kg (75 lbs) and cannot easily be used to heat rations or water.

One of the requirements of the electronically enhanced soldier of tomorrow will probably be a source of DC electrical power to recharge batteries. DC power could also be used to power a lighting system based on light-emitting diodes (LEDs). White light LEDs have recently become available and large advances in the efficiency of LEDs of all colours have been made in the last few years. The same light as a household 60 W light bulb can be produced by an array of LEDs from less than 6 W of 12 V DC power. These solid-state light sources are far more robust than the Coleman lantern which has a very fragile mantle that must be replaced after almost every camp move. An LED-based lighting system could potentially replace the naphtha-fuelled lantern and provide light, red or white, at a flick of a switch.

On northern winter exercises, military units are often joined by the local Ranger patrol. Like many other people in northern Canada, the Rangers use a wood to heat their tents in the winter. The Rangers, who travel by snowmobile, don't rely on issued naphtha stoves to heat their tents; rather, they prefer to use portable wood-burning stoves. One big advantage to a wood-stove over a naphtha-burning stove is that it does not have to taken out of the tent into the cold and dark to be refuelled; another is that the fuel can be stored inside the tent and it doesn't have to be carried, as it is locally available in much of the country.

The makers of the tent of Fig. 4 produce a stainless steel folding stove for it. The stove can be carried in a backpack and weighs only 3.6 kg (8 lbs), stovepipe included. Such a stove could also be used in the present 10-person tent. Even if this stove were only fired for an hour or two every few days, its dry heat would help to dry the collected frost and moisture out of the tent. In an environment where dry wood is not easily available, such as the Eastern Arctic, this might be done with the combustible materials from ration packs. The technology exists to thermoelectrically generate enough electricity from a wood stove to run small appliances and lights (Varmaraf Innovative Technology, Iceland). Smoke and the smell of burning wood might be tactical problems however. There would also be a significant burn hazards from the stove and its red-hot chimney in the crowded conditions of a group tent.

Discussion

Group Tent

In the near term, the functioning of the door zippers in extreme cold might be improved by the simple addition of a thick layer of insulating material on the outside of the zipper flap of the CF 5 and 10 person tents. With insulation, the heat of the interior would keep the zippers warmer, reducing icing, at least in theory. This should be tested in the field.

Zipper insulation could also be supplemented by adding a vestibule in front of the doorway. This might be a semicircular awning attached to the wall of the tent around the awning's upper half circumference. It would have no noisy or problematic closure; the users would simply lift it, step inside its footprint and then pull it down behind them.

Perhaps the only way to completely solve the problem of icing zippers is not to use zippers. Even without icing, zipper operation requires some manual dexterity, two hands, and time. Any replacement door would have to be relatively silently operating, operable with one hand and not effected by frost and ice. Ideally, it should open instantly for immediate exit in an emergency. A novel tent entrance system that might satisfy these requirements is the subject of recent report of invention by the author, pursuant to section 4 of the Public Servants Inventions Act, and so cannot be further described at this time.

In the near term, the lining of the current tent should be altered to provide adjustment capacity to ensure that it fits the tent optimally for maximum heat retention. This would take just a few extra drying line eyelet "button holes" and extra holes or grommets for the toggles.

In the medium term, the complexity of the liner could be reduced to facilitate construction and to reduce its weight. The liner is not subjected to the same stresses as the outer tent wall and probably doesn't need to be as robustly constructed and extensively reinforced as it is now.

The acceptability of a very low profile tent should be established. A much lower tent, in which there is no place to stand, but in which everyone could lie down, would have several advantages (Osczevski 1989). Chief among these are that it would be easier to heat and to hide. It might also be more comfortable to live in, lighter and less affected by wind.

Modular Shelter System

A modular tent complex that would allow independent mobility of three section elements or squads is feasible. A simple way to try it out would be to produce three tunnel tents that could be connected together along their axis to house up to 13 soldiers. This shelter complex would still have a large surface area for heat transfer, but the occupants would retain many of the social benefits of a group tent. As each module is large enough to be heated safely, condensation should not be as big a problem as it would be in a complex composed of a large central hub and smaller, unheated sleeping tents.

Sleeping bags

Adding a cold trap to collect condensation would undoubtedly add to the cost, the weight and the packed bulk. Because vapour barriers are also barriers to the diffusion of CO_2 and O_2, sleep in cold conditions might not be restful in a sleeping bag equipped with a cold trap, if individuals sleep with their head inside the sleeping bag. Perhaps a more cost effective and safe solution is to provide a convenient way to dry sleeping bags periodically in the field to solve moisture problems.

Tent Heating

The two-burner stove currently used for cooking and heating can become a fire hazard when used in extremely cold weather. Its orange-tinged flame suggests that it might be producing unburned hydrocarbons and soot even during normal operation. Small amounts of water in the fuel can also create an orange, sooty flame. Two-burner camping stoves from other manufacturers should be evaluated for this role. Mountain Safety Research is currently working on a two-burner stove based on its Whisperlite stoves. Replacing the burners with ones that produce a cleaner blue flame might reduce the incidence of eye and lung irritation. This is particularly important if the combustion products of cooking and heating cannot be vented.

Ideally, the stove should not be vented directly into a living space. Because there are other sources of water, such as steam from cooking or even just the breathing of the occupants, some way to introduce dry heated air into the shelter should be provided. A tent furnace could solve the condensation problems in both the tent and sleeping bags. It would provide hot, dry air, either re-circulating the inside air or heating dry fresh air drawn from outside the tent. A tent furnace would have four main parts: two or more burners vented by a flue to the outside; a system to convert heat to mechanical or electrical power; a heat exchanger with a blower; and ducts to distribute the hot air in the tent or to items that require drying, such as sleeping bags, and to bring cold outside air to the combustion chamber and to the intake of the heat exchanger.

At least initially, a modular approach should be used, based on the existing two-burner stove (or an improved version) as the heat source. The blower/heat exchanger module should be removable so the stove can be used for cooking. This way, in the event that the furnace module becomes inoperative, the stove could still be used to heat the tent much as it is today.

The next step is to demonstrate the feasibility of a tent furnace by producing an engineering model using the existing two-burner Coleman stove as a heat source. It would probably not be self-powered but would use an external power source such as the motor generator of Fig. 9 or the battery of a nearby snowmobile to power the blower, charge batteries and to run an LED lighting system. This would allow us to evaluate the benefits of forced air heating and solid-state lighting in a tent-group situation and to identify any potential problems.

The longer term, depending on the outcome of the feasibility trial, would see the development of a self-powered tent furnace. This might use a Stirling engine to power a blower and to generate a small amount of power for lights and battery charging, or a combination of Stirling engine and thermoelectric modules.

Recommendations

- Develop an engineering model of a forced air heating system as an add-on module to a two-burner stove.
- Evaluate a 12V DC LED lighting system as a replacement for the naphtha-fuelled lantern.
- Evaluate technologies for generating and storing DC power in a tent to run the furnace and lighting system.
- Construct a modular tent complex based on three tunnel tents, at least one of which should have the proposed new quiet and easy entry system.
- Evaluate these systems on field trials in extreme cold or military exercises.

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(U) Much of the frost and ice that form on the inside of the tent comes from water produced by the combustion of naphtha fuel in the heating, lighting and cooking systems. Frost also accumulates in sleeping bags when used in extreme cold and cannot be removed or dried with the present shelter heating system. Modifications to the group shelter are recommended to increase warmth and minimize problems with closure systems. These include an adjustable liner, insulation on the door zipper and more radical changes to the tent opening to eliminate zippers entirely. Moisture management in tents and sleeping bags is discussed. Recommendations for changing the tent heating/lighting system to improve moisture management are outlined. The major recommendation is a small forced−air tent furnace to dry the tent and large items such as sleeping bags. As envisioned, it would be based on the existing stove, but would generate its own power as well as DC electrical power to run a lighting system and to recharge batteries.

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(U) shelters; modular tents; tents; sleeping bags; condensation; heating; lighting; ventilation; cold weather; heat transfer; winter; wind; tent furnace; stoves; frost

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