Frost in Arctic sleeping bags

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Abstract

After many nights in extreme cold weather, ice builds up in the insulation of sleeping bags making them much heavier and colder to sleep in. The history of sleeping bag use in extreme cold is reviewed and the possible sources of this water are described. Quantitative investigations reveal that the weight gain during field use is highest during the first couple of nights and then reduces to a constant value. Laboratory experiments with a device simulating a warm occupant show that at –30 ºC, only 30% of the water that evaporates manages to diffuse through the bag. Internal vapour barriers and external waterproof but water vapour permeable coverings may be useful in some conditions, but the polymer coatings of outer coverings are not as permeable in the cold as they are at room temperature, while the coatings of some vapour barriers become more permeable when subjected to the warmth and high humidity in a well insulated sleeping bag. Much of the problem probably stems from warming the tent and melting the frost in the sleeping bag, then letting it refreeze in a compressed condition when not in use. One strategy that has proven successful is to never let the sleeping bag get warm enough to melt the frost that has formed in its outer layers, however this might be impractical in a military setting. It might be possible to construct the bag and/or the insulating layer so that frost can be physically removed, or so that it causes no problems if it melts.

Résumé

Après de nombreuses nuits de froid intense, de la glace s’accumule dans l’isolation des sacs de couchage, ce qui les rend beaucoup moins légers et moins chauds. On analyse l’utilisation des sacs de couchage dans des conditions de froid intense et on décrit les sources possibles de cette eau. Des études quantitatives révèlent que le gain de poids d’un sac de couchage culmine pendant les deux premières nuits pour diminuer ensuite et s’établir à une valeur constante. Des expériences en laboratoire effectuées avec un appareil simulant la chaleur qui émane d’une personne dans un sac de couchage montrent qu’à – 30 ºC, seulement 30 % de la vapeur d’eau s’échappe du sac. Les membranes pare-vapeur internes et les couvertures externes imperméables à l’eau mais perméables à la vapeur d’eau peuvent être utiles dans certaines conditions. Les revêtements en polymère des couvertures externes ne sont toutefois pas aussi perméables dans des conditions froides qu’à la température ambiante, tandis que dans un sac de couchage bien isolé, les revêtements de certaines membranes pare-vapeur deviennent davantage perméables dans des conditions chaudes et très humides. Le gros du problème se produit probablement lorsqu’on réchauffe la tente et que la glace qui s’est formée dans le sac de couchage fond puis gèle de nouveau lorsque le sac est comprimé et inutilisé. Une solution efficace consiste à ne jamais laisser le sac se réchauffer suffisamment pour que la glace accumulée dans les couches externes du sac puisse fondre, ce qui pourrait, cependant, s’avérer peu pratique dans un contexte militaire. Il serait également possible de fabriquer un sac ou une couche isolante qui permet à l’utilisateur d’enlever la glace ou de laisser la glace fondre sans que cela ne cause de problèmes.

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Executive summary

Explorers and modern adventurers have long been plagued by problems caused by frost, ice and liquid water in their sleeping bags after many nights in extreme cold weather. This history is reviewed. Ice builds up in the insulation making it much heavier, stiff, and colder to sleep in. The possible sources of this water include sweat evaporating from the skin of the user that condenses or sublimates in the insulation, water from wet clothing worn or dried in the bag during the night, water vapour from the air in the tent that diffuses into the bag and condenses and water or frost that falls from the tent ceiling. Quantitative investigations reveal that the weight gain during field use is highest during the first couple of nights and then reduces to a constant value of about 50 g per night. This is probably because of a significant reduction in insulation value on the second or third day when the damp sleeping bag has been left in a compressed state to freeze. Laboratory experiments with a device simulating a warm occupant show that at –30 ºC, only 30% of the water that evaporates manages to diffuse through the bag, and that an average of 15 g condenses in the insulation of the sleeping bag each hour. Internal vapour barriers and external waterproof but water vapour permeable coverings may be useful in some conditions, but the polymer coatings of outer coverings are not as permeable in the cold as they are at room temperature, while the coatings of some vapour barriers become more permeable when subjected to the warmth and high humidity in a well insulated sleeping bag. One strategy that has proven successful with highly motivated individuals is to never let the sleeping bag get warm enough to melt the frost that has formed in its outer layers. This means that all people in the tent must get out of their bags, pack them and put them outside before lighting any stoves, which might be impractical in a military setting. It might be possible to construct the bag and/or the insulating layer so that frost can be physically removed, or so that it causes no problems if it melts.

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Sommaire

Les explorateurs et les aventuriers contemporains connaissent depuis longtemps les problèmes causés par le givre, la glace et l'eau qui se forment dans leur sac de couchage après avoir passé de nombreuses nuits dans des conditions de froid intense. Ces problèmes ont été étudiés. De la glace s'accumule dans l'isolation et rend le sac de couchage beaucoup plus lourd, plus rigide et plus froid. Cette eau peut notamment provenir de la transpiration qui s'évapore de la peau de l'utilisateur et qui se condense ou se sublime dans l'isolation, de l'eau contenue dans des vêtements humides portés ou séchés dans le sac pendant la nuit, de la vapeur d'eau qui est présente dans l'air de la tente et qui se répand et se condense dans le sac, ainsi que de l'eau ou du givre qui tombe du toit de la tente. Des études quantitatives révèlent que le gain de poids du sac de couchage culmine pendant les premières nuits pour diminuer ensuite et s'établir à une valeur constante d'environ 50 g par nuit. Cela se produit probablement parce que l'isolation diminue de manière significative pendant la deuxième ou la troisième journée durant laquelle le sac humide empaqueté gèle. Des expériences en laboratoire effectuées avec un appareil simulant la chaleur qui émane d'une personne dans un sac de couchage montrent qu'à – 30 ºC, seulement 30 % de la vapeur d'eau s'échappe du sac et qu'en moyenne, 15 g d'eau se condense dans l'isolation du sac de couchage à chaque heure. Les membranes pare-vapeur internes et les couvertures externes imperméables à l'eau mais perméables à la vapeur d'eau peuvent être utiles dans certaines conditions. Les revêtements en polymère des couvertures externes ne sont, toutefois, pas aussi perméables dans des conditions froides qu'à température ambiante, tandis que dans un sac de couchage bien isolé, les revêtements de certaines membranes pare-vapeur deviennent davantage perméables dans des conditions chaudes et très humides. Une solution efficace consiste à ne jamais laisser le sac se réchauffer suffisamment pour que le givre formé dans les couches externes du sac puisse fondre. Ainsi, il faudrait que toutes les personnes couchant dans la tente sortent de leurs sacs de couchage pour ensuite les empaqueter et les déposer à l'extérieur avant d'allumer un poêle, ce qui n'est pas pratique dans un contexte militaire. Il serait également possible de fabriquer un sac ou une couche isolante qui permet à l'utilisateur d'enlever la glace ou de laisser le givre fondre sans que cela ne cause de problèmes.

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Introduction

A warm sleeping bag is a vital part of the equipment of anyone who travels off-road in cold regions. It is more than just survival insurance; a warm sleeping bag is a refuge. A noted polar explorer once remarked:

> "Thank Heaven it is warm and comfortable in the bag, or this sort of life would be intolerable (Nansen 1898)."

As the nights pass, however, sleeping bags tend to become less warm. Eventually, the quality and quantity of sleep suffers. The frequency of dream sleep decreases sharply and vigilance and judgement decline after a series of dream-deprived nights (Buguet A.G.C. 1976). During the day, when such an individual is warm and relatively inactive, he might fall asleep unexpectedly and begin to dream. This was experienced by a member of what was described as "the worst journey in the world", a long man-hauling sledge journey in the darkness and extreme cold of the Antarctic winter:

> "we had little consciousness of (having slept) and we were now beginning to drop off when we halted on the march. Our sleeping bags were really bad now, and it already took a long time to thaw a way down into them at night. (Cherry-Gerrard 1965)

Another member of the party, Dr. Edward Wilson, described the state of their sleeping bags after weeks at air temperatures as low as –57 °C:

> "All our bags were by this time so saturated with water that they froze too stiff to bend them with safety, so from now onwards to Cape Evans we never rolled them up, but packed them, one on the other full length, like coffins, on the sledge" (Scott 1913).

On returning to base camp after thirty-six nights, each reindeer skin and eiderdown sleeping bag combination weighed 20.5 kg, of which 12 kg was ice.

The Inuit, the experts in living in cold weather, had no use for sleeping bags. They preferred to sleep together as a family between caribou hides sharing body warmth, rather than to individually encapsulate themselves in insulated bags. Tyrell reported that the Caribou Eskimos, who inhabited the interior of Keewatin, west of Hudson Bay, sometimes used an individual sleeping bag when they went on hunting trips (Tyrell 1908). The name, "shin-in-bee", sounds enough like a corruption of sleeping bag to suggest that it was adopted technology.

Recent experience with moisture in sleeping bags

Modern day adventurers have also been plagued by the problem of moisture accumulation in sleeping bags. Twenty days out on the polar ice on his way to the North Pole in 1986, Will Steger noted:

> "I hefted my bag and found that it had gained about twenty pounds in accumulated ice. The inner layers of insulation were still somewhat dry, but the outer layers were frozen mats. We had been finding that a tremendous amount of body heat was needed to bring the bags up to a temperature at which we could sleep with minimal comfort. Some nights we shivered for three or four hours before we dozed off. (Steger 1988) "

These sleeping bags had been specially made with 5.5 kg of polyester fibrefill and had a total loft of 36 cm. They were designed with such a great thickness of insulation to compensate for the expected accumulation of ice.

After 34 days, they tried to dry the bags with stoves in the tent. Steger reported:

> "The effort proved futile. The volume of accumulated frost was now so great -- some bags weighed nearly fifty pounds -- that the minimal heat from the stoves merely redistributed the moisture rather than driving it from the bags (Steger 1988)."

In 1986, another adventurer was attempting to reach the North Pole. Sir Ranulph Fiennes made an attempt on foot, without support. Temperatures ranged from -47°C to -25°C. During this man-hauling expedition he used an experimental polyester fibrefill sleeping bag (DREO-X). He combined it with a separate waterproof breathable cover and an interior vapour barrier. Despite these precautions, his 5.5 kg sleeping bag gained 2 kilograms in sixteen nights. However, this amount of water did not make the bag uncomfortably cold or noticeably wet (Osczevski 1986).

His companion used commercial down-filled sleeping bags, with a GoreTex™ outer shell and was often cold. After two weeks, both of these bags appeared to be wet and the filling material had become permanently compressed and was frozen into lumps.

Two years later, in the spring of 1988, a team of Canadian and Soviet skiers crossed the Arctic Ocean from Siberia to Ellesmere Island. At first, all thirteen member of the Polar Bridge Expedition slept and ate in a single tent. After a couple of nights, two of the Canadians moved out to sleep in shelters made of snow. Richard Weber, who had served his polar apprenticeship on the Steger expedition, was one of the "outside men". Weber's observations are particularly interesting. He noted on Day 5 that:

> "All of the Soviets' sleeping bags, and indeed everyone's who sleeps in the tent, are losing loft; the feathers are getting wet, and the bags are getting thinner and thinner."(Weber 1990)

Laurie Dexter, an "inside" Canadian noted in his diary after three weeks that:

> "The top of my bag is little more than a few layers of nylon fabric, with fist-sized or smaller lumps of frozen down scattered along the edges!"(Weber 1990)

The sleeping bags that were used in the tent were sodden with water. Weber was disgusted by the conditions:

> "It is so horrible in there. Every meal it is the same. We sit down and get rained on. Chris [Holloway, the other 'outside man'] wears his GoreTex™ pants to keep dry. This morning I brought my sleeping pad into the tent to sit on. It slipped, and I ended up on Yuri's sleeping bag and completely soaked my suit right through..." (Weber 1990)

Later, on Day 38:

> "This evening I inspected Yuri's sleeping bag. It's quite solid. It consists of baffles separating icy lumps of down. There is really no insulation. He would probably be better off with a few garbage bags, since they would be lighter to carry, and just about as warm."(Weber 1990)

After a couple of weeks the effect of the different living accommodations on the sleeping bags was striking. Those bags that had been used inside the communal tent were wet, thin and cold to sleep in. The down had matted and balled, like the down filled sleeping bags used on the 1986 Fiennes expedition. The sleeping bags that had been used in unheated shelters still retained much of their loft and insulation although some balling of the down occurred around the head.

Richard Weber was back on the Arctic Ocean in 1992. The Weber-Malakhov expedition reached the vicinity of the North Pole from Ward Hunt Island in Canada, skiing over the ice without outside support. Each morning, *before lighting the stoves and warming the tent*, the members of the expedition crawled out of their sleeping bags, dressed, brushed the frost off the tent and sleeping bags and then placed the bags outside.

Weber's sleeping bag was filled with 1.1 kg of high loft down. It had an integral pad consisting of a full-length layer of closed cell foam, 1-cm thick, with an additional 5-cm layer of open-cell foam under the torso. Even though he used internal and external vapour barriers, frost still collected in the outer regions of the sleeping bag. However, because it was never allowed to warm up in a heated tent, the ice stayed as fluffy frost. Although the bag became heavier, it stayed thick and warm. Weber suspected that the frost might even have made the bag warmer, as during the coldest part of the expedition he was able sleep using only a single sleeping bag although he carried a second one to fit inside the first (Weber 1992). Weber and Malakhov have since made the round trip from Ellesmere Island to the Pole and back again, using only those supplies that they had with them when they first left land.

Sources of water in sleeping bags

The ice in sleeping bags can come from several sources. The body, which is essentially a vapour permeable bag of warm water, is a source of water vapour even when not sweating. This vapour diffuses into the sleeping bag where it condenses or freezes out in the cold outer layers of the insulation.

If the sleeping bag has too much insulation, the user will actively perspire. The sweat will evaporate from the skin and sublimate or condense everywhere in the sleeping bag, especially in the cold layers of insulation that are remote from the body's warmth.

Water vapour can also come from the breath. In really cold weather, whether they realise it or not, people draw their faces into the bag to breathe the warmer air inside. This not only adds to the water vapour in the interior, it reduces the rate at which the sleeping bag is ventilated. Because the chest volume increases while breathing in, the volume of air spaces between the occupant and the sleeping bag (in some postures) decreases. This forces air to flow out of and then back into the sleeping bag on expiration. If the sleeper breathes from the internal airspace, there is no such flow as the volume drawn into the lungs matches the decrease in air space volume.

Even if the sleeper breathes outside the bag, the water vapour in his breath condenses on its cold outer surfaces or on the cold tent walls. When the tent is warmed in the morning this frost melts and soaks into the bag or drips onto it from the tent above. Water from the combustion of hydrocarbon fuels will usually condense on the cold walls of a tent and might drip off or be shaken off by gusts of wind. Water is a by-product of combustion of hydrocarbon fuels in stoves and lanterns. It is produced in amounts that exceed the mass of fuel consumed when the hydrogen atoms in the fuel combine in the flame with oxygen from the air.

Water can also get into sleeping bags directly from the humidity in the air of a heated tent, even though the relative humidity of the air may be quite low (Osczevski 1979). If an unoccupied sleeping bag is left lying on the tent floor, the insulation in its lower regions will rapidly cool to a temperature between that of the tent and the cold ground or snow on which it lies. Unless there is a vapour barrier between the insulation of the sleeping bag and the warm, humid air of the tent, water vapour will diffuse into the insulation in the direction of the temperature gradient from warm to cold and condense or form frost in the colder filling material.

Finally, the practice of drying damp clothing by wearing it while sleeping also adds water to the insulation in the bag. The maxim that it is warmer to sleep naked in a sleeping bag might have something to do with water accumulation from clothing in the long term, but probably, it has more to do with drafts or air leaks that steal heat. These are immediately sensed by bare skin and corrective action is taken. The sensation of a cold draft forces the sleeper to make adjustments to minimise the leaks. If clothing is insulating the skin the sensation of a cold leak may not be intense enough to stimulate the necessary corrective action.

Quantitative investigations

A quantitative assessment of moisture accumulation in sleeping bags was reported in 1950. Six sleeping bags used by American soldiers in a tent at Fort Churchill, Canada were weighed daily during a nine-day trial (Eliot 1950). The temperature varied from -12°C to -31°C. The average mass increased most quickly the first night, by 200 g. For the next six nights the moisture accumulated at an average rate of 50 g/night. Thereafter it decreased by about 25 g/night.

The same year, Wilson and Blouin reported a longer-term measurement of moisture accumulation. The data was collected during an expedition to Baker Lake, N.W.T., Canada (Wilson 1950). During the four-week period from mid-February to early March, the three participants, L. G. Wilson, A. E. Blouin and A. G. Reid lived in a five-metre diameter snowhouse (igloo). The ambient temperature during the night ranged between -18°C and -43°C and averaged -34°C ± 6°C. The lowest temperatures were accompanied by the high winds for which the Barrens are noted.

When the snowhouse was heated, the temperature at the level of the sleeping platform, 55 cm above the floor, averaged -4°C ± 2°C. The temperature dropped after the stoves were extinguished in the evening so that by morning it averaged -15 ± 4 °C. This was still about 20 °C warmer than the temperature outside. The snowhouse was heated for 9 to 10 hours per day at the expense of about four and a half litres of fuel.

The large commercial sleeping bags weighed an average of 7.5 kg when dry. They were used on the sleeping platform, which had first been covered by two layers of caribou skin. Air mattresses were placed between the skins. The sleepers wore a duffle parka, reserved for the igloo, and a pair of pile trousers that had been worn outside during the day for a two to five hour period.

After the bags had been used for a week, they were weighed daily with a spring scale to the nearest 50 g., each morning. On the first weighing, they were an average 200 g heavier than the dry weight. They continued to gain weight at an approximately constant rate of 55 g/night until they had accumulated 500 g of water. After this point, the rate of weight gain slowed considerably. One bag lost weight and levelled off at an increase of 400 g, and another continued to gain weight slowly so that after a total of twenty-four nights it had accumulated 650 g of moisture.

When the weight gain of a third bag reached 500 g, its occupant began to have trouble staying warm enough to sleep, even though the temperature on the sleeping platform was only -18°C. After a couple of restless nights, he switched to a new sleeping bag. After the first night in this bag, it was 250 g heavier than when it was dry. For the next two nights it gained an average of 80 g/night. Afterwards, it gained weight at a rate of less than 10 g/night.

In 1974, the daily accumulation of water in Canadian Forces extreme cold weather sleeping bags was measured during a trial near Ottawa, Canada (Osczevski 1983). The night low temperature varied from -7°C on the first night to -29°C on the fourth and final night. The mass increased most rapidly on the first night, by an average of 170 g. Afterwards, it increased by an average of only 40 g/night.

Moisture accumulation in an experimental sleeping bag (DREO-X), which used a continuous filament polyester insulating material (PolarGuard©), has been measured on several occasions. These bags have 10 cm of insulation over the body and an insulating pad of about half that thickness beneath. In 1986, the weight gain of one of these bags was monitored on a daily basis during a winter journey along the coast of James Bay. The temperature during this trial varied between -5°C and -30°C. On the first night in the unheated tent it gained 175 grams. For the next seven nights it gained an average of 50 g/night, following the now familiar pattern. One member of the party used a Canadian Forces down and feather sleeping bag on a pad of closed cell foam and a self-inflating air mattress. Over the same period, it gained only 250 grams. At times however, its occupant was uncomfortably cold in contrast to the happier users of the experimental sleeping bag. At the time, the only other sleeping bag of this design was keeping Sir Ranulph Fiennes warm on the Arctic Ocean.

A similar trial was carried out three years later (Osczevski 1989). The night temperatures during the trial varied from -14°C to -32°C. This time only the DREO experimental sleeping bags were used. Three were used inside of vapour-permeable, waterproof covers (bivouac sacks). Two of these bags picked up 570 grams and 450 grams in eight nights of use. The third, which had a chance to dry on the second night, gained 370 grams. The fourth sleeping bag was used without a cover. It gained only 290 g. Since the bottoms of the bivouac sacks did not become noticeably wet, the added mass is assumed to have been water condensed in the insulation and/or between the bag and the sack. As the "control" bag without the bivy-sack was used directly on the snow, some of its mass increase may have been ice that was picked up from the snow floor of the tent. This trial used a tent that had been designed prevent the dripping of water when heated in the morning.

Laboratory experiment

The accumulation of water in one of the DREO-X sleeping bags has been studied in the laboratory. A device was constructed which would evaporate water at approximately the same rate and at the same temperature as a human occupant. It consisted of a shallow pan covered with a polyester cotton fabric that was coated with Dermoflex®, a waterproof but vapour permeable coating. The cover was permeable to water vapour but waterproof. A wicking material covered the pan's inner surface. Distilled water in the pan was maintained at a constant temperature of 40°C by means of heaters and a proportional temperature controller. Areas of the covering fabric were masked with silicone sealant to reduce evaporation to between 10 to 30 g/m^2h depending on room humidity. The permeable surface area of the pan, 0.22 m^2, is about one ninth of the surface area of a human being.

The heated pan was placed on an electronic scale inside the sleeping bag, which was inside a walk-in cold chamber at a temperature of –30 °C. Arches of rigid sheet moulded polystyrene foam supported the top of the sleeping bag so that the weight of the top of the sleeping bag did not bear on the pan. The opening of the sleeping bag was closed with a block of polystyrene foam, 5 cm in thickness, around which the draw cord was tightly pulled.

The mass of the pan was recorded at intervals during a two-day period. The air temperature in the cavity inside the sleeping bag was almost constant at 21 °C to 22 °C. The bag was weighed before the test began and at its end (Fig. 1). Only 30% of the water that evaporated from the pan was able to escape from the sleeping bag. The other 70%, condensed as frost in the insulating material, at a constant rate of 15g per hour. Thus in eight hours, the bag picked up about 120 g, which is of the same order as the first night rate in field trials.

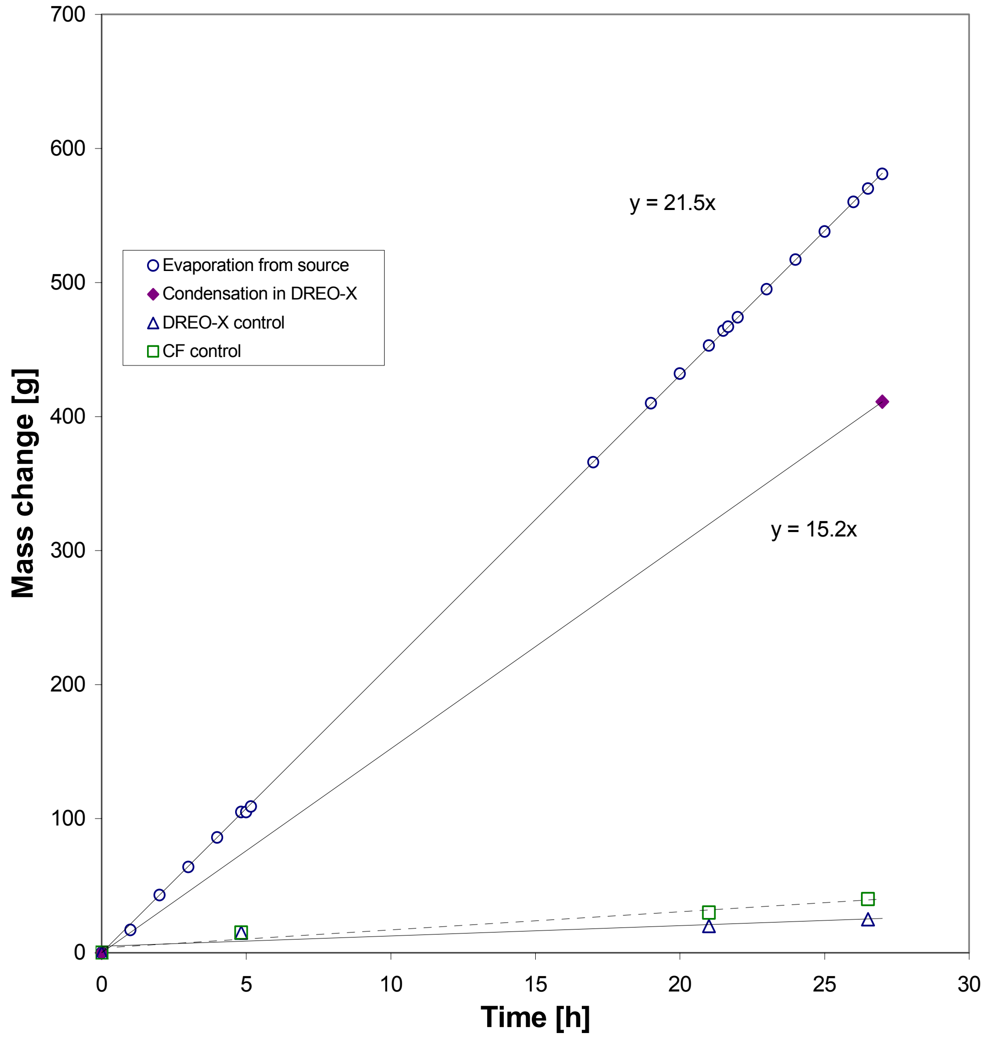

Figure 1. *Accumulation of water in a continuous filament polyester filled sleeping bag at –30 ºC*

The heat required to maintain the internal temperature at 40 ºC was a constant 70 watts, which is in line with human heat production in similar circumstances. Since evaporation was a significant part of the heat loss of the pan, a human occupant might have to sweat at temperatures warmer than –30 °C in this sleeping bag, if there were no other losses from respiration, etc. This might explain why sleeping bags with internal vapour barriers sometimes feel uncomfortably muggy.

Discussion

A consistent pattern of weight gain has been seen in quantitative trials. There is an initial high gain of weight on the first night of use followed by a lengthy period during which the moisture accumulates more slowly and may eventually seem to reach a steady state. This is not because the moisture regain of the insulating materials has increased, for the effect is no larger in a down and feather sleeping bag than it is in a sleeping bag with less hydrophilic synthetic filling materials.

Down is more dramatically affected by moisture accumulation than synthetic battings. The "inside" bags of the Soviet/Canadian polar crossing picked up water either from the atmosphere of the tent when it was heated or were wetted by water dripping off the tent walls. The down in these bags collapsed into frozen balls occupying only a small portion of the down channel. Although sleeping bags from both locations undoubtedly contained water, the water in the “outside” bags stayed as frost. Because the "inside" bags spent some time each day in a warmed tent, some or all of the frost they contained melted. Later, when the wet bags were packed and carried outside, the wet down froze in the compressed state. When next used, the insulation stayed as scattered frozen lumps of fibre-reinforced ice until thawed by body heat. Since the bags had little insulation in this state, there often wasn’t enough body heat to do the job completely.

The DREO experiment with protective outer covers suggests that a covering of waterproof, water vapour permeable material may be of little or no net benefit when used inside a dry tent in very cold weather. If water drips from the ceiling and walls of the tent, there may be some benefit to a breathable cover that is at least water repellent. When a water vapour permeable cover is used, water can accumulate from the body during the night when the cover is cold, and from the warm air in a tent or from a wet outer shell in the morning when the cover is warm. Some waterproof but water vapour permeable materials such as GoreTex™ II are not nearly as "breathable" with respect to water vapour when they are cold. They are also almost impermeable to oxygen or carbon dioxide, which is important when attempting to sleep with the head pulled inside the bag (Osczevski 1995).

Vapour barriers are often used in an attempt to keep water vapour from condensing in the insulation. Ordinary polyurethane coated fabrics are not sufficiently vapour proof for the job. Next to the body in a sleeping bag, they are in warm, humid air. Both of these factors increase the permeability of the coating.

When vapour barriers are used inside sleeping bags, they are often perceived to be uncomfortably hot. This suggests that sweating and evaporation at the skin surface may be important in maintaining local heat balance in well-insulated sleeping bags. If evaporation of sweat is necessary, the sleeping bag has too much insulation, at least initially. Mean skin temperature usually rises on entering a sleeping bag and stays high for a couple of hours. It has been measured as high as 34.5 °C in the CF Arctic bag (Bouget et al. 1976).

The total insulating value of a sleeping bag may be much lower after it has been once used and sweated in, especially if it has been thawed and subsequently packed up and allowed to freeze. This might account for the much lower moisture accumulation rates after the first night of use – the users are simply sweating less because the bag is no longer as warm as it once was during the first few hours.

Conclusion

A vapour barrier lining should, in theory, keep water out of the insulation. However, some ordinary polyurethane coatings that are a vapour barrier at room temperature in a standard test apparatus, become too permeable to water vapour when they are in a warm, humid environment like that of a sleeping bag. Different coating materials will have to be evaluated for this role.

From the evidence of polar explorers and recent adventurers it appears that sleeping bags, particularly down-filled sleeping bags, should not be allowed to warm up if they are to be used for many nights. If a bag is allowed to warm up in a heated tent, the frost in the outer layers will melt, soak the insulation and wick or diffuse back down into the inner layers of the bag. The next time the bag is used re-melting the ice in the inner layers will take a great deal of heat from the body and more heat will be lost by evaporating this water as the inner layers dry. Most of this water vapour will condense as water or frost in the colder outer layers. Thus at first the bag will seem cold, but once the inner layers have been dried by body the bag should be less uncomfortable. At some point, however, too much time and body heat will be required to do this and the quantity and quality of sleep will suffer.

Packing a wet bag and allowing it to freeze in the compressed state creates lumps of fibre-reinforced ice, which are very poor insulation. For long-term use, synthetic fibrefill insulation may be preferable, at least for the outer regions of a sleeping bag.

If the bag stays cold, any moisture that has accumulated will stay as frost in the bag's outer regions. This solution to the problem will require dedication and faith on the part of the user. While enduring the short-term pain of getting out of a warm sleeping bag into a tent that is only slightly above ambient temperature, the vast majority of users will probably find it difficult to see the long term gain.

Sled dogs and many other polar animals sleep in insulating covers (fur) that are constructed so that any frost that accumulates during the night can be shaken out on arising. It may be practical to use insulating materials or construction techniques that make it possible to remove the frost that has accumulated overnight in the outer regions of the sleeping bag. Ideally, this would be done in the morning, while still in the shelter of the sleeping bag and before the shelter or tent is heated.

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14. ABSTRACT

(U) After many nights in extreme cold weather, ice builds up in the insulation of sleeping bags making them much heavier and colder to sleep in. The history of sleeping bag use in extreme cold is reviewed and the possible sources of this water are described. Quantitative investigations reveal that the weight gain during field use is highest during the first couple of nights and then reduces to a constant value. Laboratory experiments with a device simulating a warm occupant show that at –30 ºC, only 30% of the water that evaporates manages to diffuse through the bag. Internal vapour barriers and external waterproof but water vapour permeable coverings may be useful in some conditions, but the polymer coatings of outer coverings are not as permeable in the cold as they are at room temperature, while the coatings of some vapour barriers become more permeable when subjected to the warmth and high humidity in a well insulated sleeping bag. Much of the problem probably stems from warming the tent and melting the frost in the sleeping bag, then letting it refreeze in a compressed condition when not in use. One strategy that has proven successful is to never let the sleeping bag get warm enough to melt the frost that has formed in its outer layers, however this might be impractical in a military setting. It might be possible to construct the bag and/or the insulating layer so that frost can be physically removed, or so that it causes no problems if it melts.

(U) Après de nombreuses nuits de froid intense, de la glace s'accumule dans l'isolation des sacs de couchage, ce qui les rend beaucoup moins légers et moins chauds. On analyse l'utilisation des sacs de couchage dans des conditions de froid intense et on décrit les sources possibles de cette eau. Des études quantitatives révèlent que le gain de poids d'un sac de couchage culmine pendant les deux premières nuits pour diminuer ensuite et s'établir à une valeur constante. Des expériences en laboratoire effectuées avec un appareil simulant la chaleur qui émane d'une personne dans un sac de couchage montrent qu'à –30 ºC, seulement 30 % de la vapeur d'eau s'échappe du sac. Les membranes pare-vapeur internes et les couvertures externes imperméables à l'eau mais perméables à la vapeur d'eau peuvent être utiles dans certaines conditions. Les revêtements en polymère des couvertures externes ne sont toutefois pas aussi perméables dans des conditions froides qu'à la température ambiante, tandis que dans un sac de couchage bien isolé, les revêtements de certaines membranes pare-vapeur deviennent davantage perméables dans des conditions chaudes et très humides. Le gros du problème se produit probablement lorsqu'on réchauffe la tente et que la glace qui s'est formée dans le sac de couchage fond puis gèle de nouveau lorsque le sac est comprimé et inutilisé. Une solution efficace consiste à ne jamais laisser le sac se réchauffer suffisamment pour que la glace accumulée dans les couches externes du sac puisse fondre, ce qui pourrait, cependant, s'avérer peu pratique dans un contexte militaire. Il serait également possible de fabriquer un sac ou une couche isolante qui permet à l'utilisateur d'enlever la glace ou de laisser la glace fondre sans que cela ne cause de problèmes.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Cold weather operations; cold weather; cold weather clothing; sleeping bags; moisture; frost; ice; accumulation; vapour barrier; water vapour; extended use