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Construction of emergency snow shelters using the results of air, snow and ground temperature measurements

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Konstrukcja awaryjnych schronień śnieżnych z wykorzystaniem wyników pomiarów temperatury powietrza, śniegu i gruntu

Streszczenie

Niniejsza praca przedstawia wykorzystanie wyników pomiarów temperatury gruntu, śniegu i powietrza do konstrukcji prowizorycznych schronień ze śniegu. W Polsce w najzimniejszych miejscach (Tatry, Kotlina Orawska) wartości temperatury na kontakcie powierzchni gruntu z pokrywą śnieżną oscylują najczęściej w przedziale od 0°C do −3°C. Dlatego przy konstrukcji schronień śnież-

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nych nie powinno się zostawiać na gruncie wewnątrz schronienia śnieżnej warstwy izolacyjnej, która blokuje ogrzewanie jego wnętrza przez ciepło zgromadzone w gruncie. Bardzo duży wpływ na temperaturę we wnętrzu schronień śnieżnych ma wielkość otworu wejściowego i wysokość jego usytuowania. Im większy otwór i wyżej usytuowany w stosunku do podłoża, tym niższe wartości temperatury i większy pionowy gradient termiczny występują wewnątrz schronienia. Temperaturę w poprawnie skonstruowanym śnieżnym schronieniu reguluje się za pomocą przysłonięcia otworu wejściowego. Grubość ścian, a zwłaszcza stropu, nie powinna przekraczać 40 cm. Ściany o grubości 30 cm zapewniają wystarczającą termoizolację.

Słowa kluczowe: schronienia śnieżne, temperatura gruntu, temperatura pokrywy śnieżnej, ratownictwo górskie, turystyka wysokogórska, Kotlina Orawska, Tatry.

Abstract

This paper presents the use of ground, snow, and air temperature measurements for the construction of makeshift snow shelters. In Poland, in the coldest places (the Tatra Mountains, the Orava Basin) the temperature values at the contact of the ground surface with the snow cover usually oscillate in the range from 0°C to −3°C. Therefore, when constructing snow shelters, a snow insulation layer should not be left on the ground inside the shelter, which blocks the heating of the shelter interior by the heat accumulated in the ground A very big influence on the temperature inside snow shelters is the size of the entrance opening and the height of its location. The larger the opening and the higher it is located in relation to the ground, the lower the temperature values and the greater the vertical thermal gradient occur inside the shelter. The temperature in a properly constructed snow shelter is regulated by covering the entrance hole. The thickness of the walls, and especially the roof of the shelter, should not exceed 40 cm. Walls with a thickness of 30 cm provide sufficient thermal insulation.

Keywords: snow shelters, ground temperature, snow cover temperature, mountain rescue, alpine tourism, the Orava Basin, the Tatra Mountains.

Introduction

The most research on the development of ground temperature and the depth of its freezing in the winter in Polish mountains has been conducted in the Tatra mountains. It was commenced over half a century ago by Hess (1963), Kłapa (1963, 1966) and Gerlach (1971). In 1994, the research on the winter ground temperature distribution and the occurrence of permafrost was conducted with the help of modern geophysical methods of BTS (the Bottom Temperature of Snowcover), vertical electrical sounding, electromagnetic, seismic and georadar sounding, infrared measurements, statistical modelling (Dobiński, 1996a, b, c, 1997a, 2011; Dec & Dobiński, 1997, 1998; Kędzia et al., 1988; Mościcki & Kędzia, 2001, 2002; Mościcki, 2008, 2010, 2011; Baranowski et al., 2004, 2005; Lamparski & Kędzia, 2007; Dobiński et al., 2008; Gądek & Kędzia, 2006, 2007, 2008, 2009; Gądek & Leszkiewicz, 2010, 2012; Gądek et al., 2013). Although the research on the winter temperature distribution in the High Tatras is continued with little pauses, its use is very sporadic. An example of practical use of this type of research was the evaluation of geotechnical conditions needed for the modernization works of the cable car to Kasprowy Wierch (Kotyrba et al., 2004). Although this type of research can be practically used in many other areas of human activity in the mountains, it rarely happens.

An example of not using the results of ground temperature studies in our country is the way snow and snow-and-plant shelters are built. From the beginning of mountain rescue services and tourism, especially alpine one, the use of snow shelters serving to survive in difficult and dangerous weather conditions has been well-known (Simpson, 1992; Więckowski, 1998; Marasek, 2016, 2019, 2020). Many alpine tourists have survived an unexpected camping experience in the mountains only thanks to digging a snow cave, a type of snow shelter. Likewise, our army uses snow shelters during its training and activities in the mountains (among all, Bernabiuk, 2007; Rybak, 2021; Gruszczak,1994; Dąbrowska, 2009; Pietraszek, 2013). Unfortunately, erecting such shelters has most often little to do with the conclusions drawn from the research on ground, snow and ground-level air temperature distribution in Polish mountains. The blame lies with an uncritical approach to many survival guides showing how the inhabitants of far-north regions, most often the Inuits, construct their snow shelters. Hence, the aim of this research is evaluating snow shelter constructions used so far and showing how they should be properly erected in relation to the results of the research on ground, snow and ground-level air temperature distribution. It is crucial to construct snow shelters properly as human health, and very often human life as well, depend on it.

State of the art

For many people, the winter season is a period of an intense activity, both professional (mountaineers, alpinists, climbing instructors, guides, mountain rescue teams' members, ski tour competitors, researchers, polar regions explorers, soldiers, etc.) and recreational one (high-mountain trekking, outdoor sports, climbing, winter tourism, etc.). In emergency situations, especially in high mountains, when the weather becomes extreme, there are exceptionally unfavourable conditions to survive. Strong winds, often coupled with a snowstorm and blizzard, significantly lower the apparent temperature. If an individual does not have proper clothing, they might suffer from hypothermia and freeze to death within a few hours (Uchmański, 1974). The only solution in this situation is building a proper shelter as fast as possible. Putting up a tent in strong wind is often impossible. Apart from that, a tent protects one from the wind but not from low temperature. The safest shelter, protecting both from the wind and low temperature, is a snow one, or a snow-and-plant one. If, due to planning mistakes, an unexpected accident, the loss of camping equipment or a sudden change of weather conditions, one has to rely on their own resources, building a winter shelter might turn out to be the only way to survive. As many real-life examples show, oftentimes snow shelters have been used in extreme situations. The history of mountain climbing is peppered with instances of ascending unclimbed peaks when snow shelters let many alpinists and Himalayan mountaineers survive the night.

Many such cases were described by M. Więckowski (1998). According to the facts presented, the participants of an unsuccessful Austrian-German expedition to Nanga Parbat in 1934 spent difficult to survive nights in the snow. During another mountain expedition to Pobeda Peak in 1955, due to strong winds combined with a snowstorm, the Kazakhs lost their tents and to survive another night they had to dig a snow cave that could shelter their twelve-person team.

Polish Himalayan mountaineers have also used snow shelters during their mountain expeditions. During the first expeditions of Polish teams, Jerzy Kukuczka and Krzysztof Wielicki with their partners were forced several times to survive a night in a makeshift igloo or a snow cave (Kukuczka: in 1974 on McKinley, in 1985 on Dhaulagiri, in 1985 on Nanga Parbat, Wielicki: in 1989 on Lhotse) (Kortko & Pietraszewski, 2016). A contemporary successful mountain climber, A. Bielecki, also spent a few days in a snow cave when the weather turned extreme during his expedition in the Tian Shan in 2008 (Bielecki & Szczepański, 2017).

Professional climbers were not the only ones to use snow shelters. In 1986, on the western coast of the United States, in the Cascade Range, a group of school children with their guide were surprised with a sudden and extreme change in weather conditions. Due to their exhaustion, they were forced to stay in the mountains and seek shelter in a snow cave they dug (Więckowski, 1998). Similarly, in 1972, after climbing Mont Blanc, a group of English climbers was stuck on the mountain due to bad weather. They spent a few days in snow caves. Unfortunately, a long waiting time, soaked sleeping bags and exhaustion resulting from high altitude finally defeated the climbers. They were found dead by French guides (Więckowski, 1998).

Winter shelters are used not only for life saving purposes. Building snow caves might be included in the tactics of reaching summits. In order not to carry all the heavy equipment, some teams do not take tents with them, deciding to sleep in snow caves. This is what the Georgians did while climbing Pobeda Peak in 1981 (Więckowski, 1998). The same strategy was used by two British climbers during their ascent of a huge and dangerous wall of Siula Grande in the Andes (Simpson, 1988).

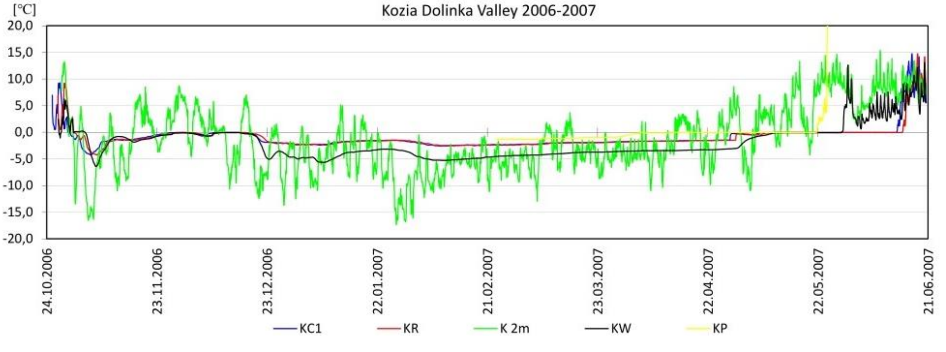
Using snow caves for survival is also practised in our contemporary times. In February 2016, two tourists did not reach the mountain shelter in the Five Polish

Lakes Valley. After a whole-night rescue action, mountain rescue team members reached the tourists who had dug a snow cave and survived in good shape (Marasek, 2016). In 2019, TOPR (Tatra Volunteer Search and Rescue) team members found a missing person and decided to dig a snow cave and safely spend the night there as the tourist was too weak to reach the shelter in unfavourable weather conditions. The next day she was transported to hospital by helicopter (Marasek, 2019). In December 2019, a group of four tourists was forced to stay in the Tatras for the night as the rescuers could not find them due to a raging blizzard. They survived thanks to digging a snow cave (Marasek, 2020). Likewise, three tourists who got stuck in the evening on Kopa Kondracka on 21 January 2022 rescued themselves by digging a snow cave. At night the temperature dropped to -17 °C. The tourist spent the night in the cave and only the next day in the afternoon were they led down by the rescuers (Marasek, 2022).

As it is shown, one can find many examples of using snow shelters. There is a hypothetical question how many of them have not been described by professional literature. Additionally, it can be assumed that in many cases people lost their lives as due to lack of proper equipment or knowledge they did not construct appropriate shelters. It should be also emphasized that mountain tourism is gaining more and more followers, which the statistics of Tatra National Park clearly illustrate (tpn.pl, 2023).

While constructing snow shelters, people follow their own intuition or use instructions for shelter designs from survival guides written in majority by foreign authors (among all, Headquarters, Department of the Army, 1968, 1986, 2002, 2016; Jankowsky, 1986; U. S. Marine Corps, 1988; McManners, 1994; Darman, 1996; Graydon & Hanson 1997; Lewis, 1997; Marshall, 1997; Kochański, 1999, 2016; Wiseman, 1999, 2010; Fowler, 2005; Swedish Armed Forces, 2005; McNab, 2008a, b; McPherson, 2008; Rogers, 2012; Mastro, 2016). The biggest number of details pertaining to constructing such shelters can be found in military guides/ instructions of the Norwegian, Canadian and American Army (Chefen för Armén, 1988; Headquarters Defence Command Norway, 1989; Army et al., 1999; Department of the US Army, 2008; Norwegian School of Winter Warfare, 2010; The Finnish Defence Forces, 2017). In all shelters built from snow, the guides recommend leaving about a 30 cm layer of snow on the ground, serving as the floor, insulating from the influence of the frozen ground. At the entrance, there should be a big enough hollow in the snow floor to accumulate cold, i.e. heavier than warm, air. In foreign publications, this hollow is usually called “a trap for cold air” or “a cold air catcher”. This assumption is in accordance with an igloo construction erected by the Inuits, who tried to put their beds on a snow pulpit. In very cold areas, e.g. Alaska, north Canada, north Siberia or in some mountains, i.e. the Japanese Alps, the Himalayas where permafrost occurs and the ground temperature where it touches the bottom of the snow cover reaches very low values of minus several °C, such a construction of a snow shelter proves effective (Ishicava, 2003; Nicolscy et al., 2016). However, as the research conducted by Gądka and Kędzia (2007, 2008, 2009), Kędzia (2004, 2006), Kędzia et al., (1988) and Mościcki and Kędzia (2001, 2002) showed, only in the Kozia Dolinka Valley where permafrost occurs the BTS measured in the 90s of the 20th century equalled -8.0÷ -10.0°C. In the years to follow such a low temperature was not recorded any more (Fig. 1). In the most area of the Tatra Mountains, the BTS value oscillates between 0 °C up to about -3.0°C. In snow shelters, the temperature between -1.0°C and -3.0°C is the most desired one. Above 0°C, the walls of the shelter, especially its roof, begin to melt. The temperature value below -3.0°C is not desired either as it does not significantly impact the structure of the shelter but makes the person inside unnecessarily suffer from hypothermia.

As the ground temperature where it touches the bottom of the snow cover in Polish mountains oscillates within the range of temperature values desired in snow shelters, one should ask a question if leaving a snow layer insulating from the ground is justified. What is more, Figure 2 shows that the temperature of the snow cover above the ground might have significantly lower values than at the ground level. Thus, it is one more reason which questions leaving a snow layer insulating from the ground in a snow shelter. To put an end to these doubts, the decision was taken to field test constructing snow and snow-and-plant shelters of various structure types (Fig. 3a, b, c, 4a, b, c).



Explanation of the places chosen: KC1 – talus cone at the foot of Kozie Czuby summit, KR – talus cone at the foot of Rysa Zaruskiego, K2m – air temperature at the height of 2 m on talus cone at the foot of Kozie Czuby, KW - talus cone at the foot Kozi Wierch summit (the place of permafrost occurrence), KP – the entrance to the Kozia Dolinka Valley.

Fig. 1
Ground temperature distribution in selected places in the Kozia Dolinka Valley in the cold period of the year

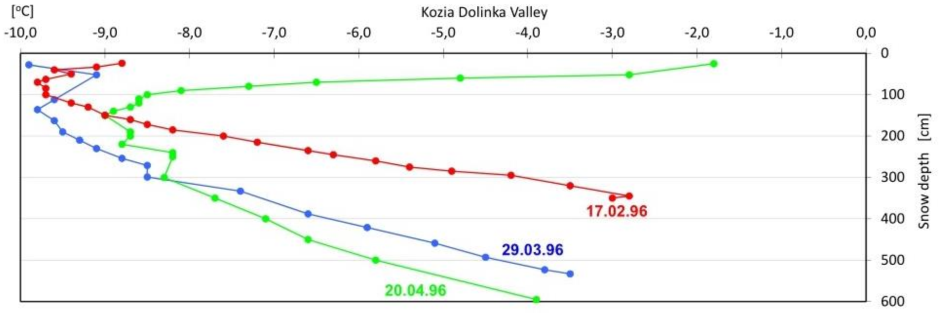


Fig. 2
Vertical temperature distribution in the snow cover in the Kozia Dolinka Valley on 17.02.1996, 29.03.1996, 20.04.1996 (Kędzia, 2005)

The area of the research and methods

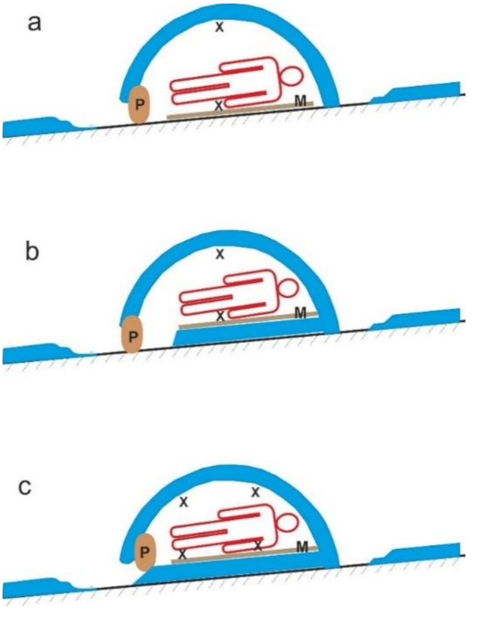
Piekielnik, a place located on the outskirts of the Orava Basin, was selected as the research area. In the Orava-Nowy Targ Valley, especially in the winter, stagnant cold air accumulates and is responsible for temperature inversion (Hes, 1965). That is why the lowest minimal temperature values are not recorded on Tatra summits but in the valleys surrounding those summits. Hence the choice of the Orava Basin as the research area. It is at its bottom that ones of the lowest minimal temperature values in Poland are recorded. The research was conducted in the period of time from 16 to 18.01.2021.

As mid-forest clearings are characterised by lower minimal air temperature values than the forest itself (Molga, 1986), the shelters were built on one mid-forest clearing of slight ground inclination (Photo 1). Each of six shelters had an air hole in the roof and a very tight entrance, located just above the ground. Ground inclination favoured gravitational indoor ventilation. The shelter types (quinzhee and snow-and-plant ones) had to be chosen because of snow conditions – powdery snow of low thickness (Photos 2, 3). In Poland, only in some places (mainly in the mountains), and only for a short period of time there is a snow cover appropriate for building a traditional igloo. In his publication of 2015, Kędzia writes more about it. The wall thickness of constructed shelters equalled about 30 cm. In five shelters, there were two Onset HOBO automatic temperature gauges installed (Fig. 3a, b, 4a, b, c). One was placed a few centimetres under a snow roof, another one a few centimetres above the snow ground. The sixth shelter (Fig. 3c) had 4 temperature gauges installed. The first two were located at the entrance (at the roof and above the ground), and the other two were placed at the end of the shelter (also at the roof and above the ground). In order to record air temperature outside the shelters, one temperature gauge was placed at the border of the forest, on a spruce branch, from the northern side. The first sensor recorded air temperature at the height of about 20 cm above the snow cover, while the second one recorded air temperature at the height of about 200 cm above the snow cover. The temperature value was recorded by all the sensors every 10 minutes. Although the sensors were new, both before and after the research they were subject to calibration which showed that within the range of a few degrees below and above 0 °C the reading discrepancy was smaller than 0.2°C. Each research participant slept in their shelter for two nights. During the day, the shelters were left empty. Before dawn, when the research participants were sleeping in their shelters, the measurements were performed with the help of a thermal imaging camera. Apart from military purposes, the measurements were to prove that the shelters' structure was correct, mainly as far as their wall thickness was concerned. For the safety of the persons sleeping in the snow shelters, self-rescue tests for a person buried in a snow shelter were also organized for them. The aim of these tests was to obtain information on the safe maximum wall thickness of a snow shelter.

Photo 1
The place where the snow and snow-and-plant shelters were built (Photo: S. Kędzia 2021)

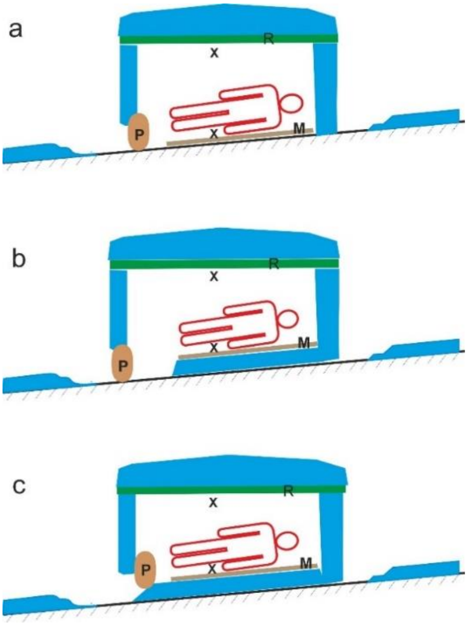
Photo 2
A quinzhee shelter type (Photo: S. Kędzia 2021)

Photo 3
A snow-and-plant shelter (Photo: M. Kalita 2021)



The meaning of symbols: x – temperature sensors, P – backpack, M – mattress. The snow is marked in blue.

Fig. 3 →
Quinzhee (quinzee) type shelters: a) without an insulating snow layer on the ground, b) with an insulating snow layer on the ground and the cold air catcher, c) with an insulating snow layer on the ground and without the cold air catcher



The meaning of symbols: x – temperature sensors, P – backpack, M – mattress, R – the roof layer built with coniferous tree branches covered with a space blanket and snow. The snow is marked in blue.

← *Fig. 4*
Plant-and-snow shelters: a) without an insulating snow layer on the ground, b) with an insulating snow layer on the ground and the cold air catcher, c) with an insulating snow layer on the ground and without the cold air catcher

Figures 5 and 6 show temperature distribution at the ground level in Piekielnik, in the place of the research. Temperature measurements were performed in two places. The temperature sensors were covered with a very thin 1–2 cm layer of the ground. In the winter season of 2019/2020, the temperature value dropped only slightly below 0 °C. It did not reach the value of -1.0 °C (Fig.

5) even once. During the next winter season of 2020/2021, the ground temperature reached its lowest values in the snowless period, i.e. in the first half of January and in March. When the snow covered the ground, the temperature value oscillated around 0 °C up to about 1.5 °C although the air temperature value at the height of 2 m over the snow cover dropped to about -20.0 °C.

The next figure (Fig. 7) illustrates the ground temperature distribution in the Kozia Dolinka Valley in the Tatra Mountains in the winter of 2020/2021. The measurement was carried out in two places situated at the height of about 1930 m above the sea level, below talus cones where permafrost occurs. Similarly to Piekielnik, the thermistors were covered with a ground layer of about 1–2 cm. The lowest temperature value slightly below -10.0 °C was recorded at the turn of November and December, just before the formation of the snow cover. When the snow cover was on the ground, the lowest temperature reached the value of about -2.0 °C. At the turn of April and May the snow started to melt and the ground temperature equalled 0 °C up till mid-July when the snow in the measurement place completely melted.

The research conducted both in highly located Kozia Dolinka Valey in the Tatra Mountains and in one of the coldest places in Poland, i.e. the Orava-Nowy Targ Basin proves that the ground temperature during the occurrence of the snow cover most often oscillates within the range of 0 °C up to about -2.0°C. In some places where permafrost occurs in the Tatra Mountains, the ground temperature reaches lower values (Dobiński 1996a, b, c, 1997a, 2011; Kędzia et al., 1998; Kędzia, 2004, 2006; Mościcki & Kędzia, 2001, 2002; Gądek & Kędzia, 2008, 2009). However, these are very few places and not all of them are suitable for building snow shelters.

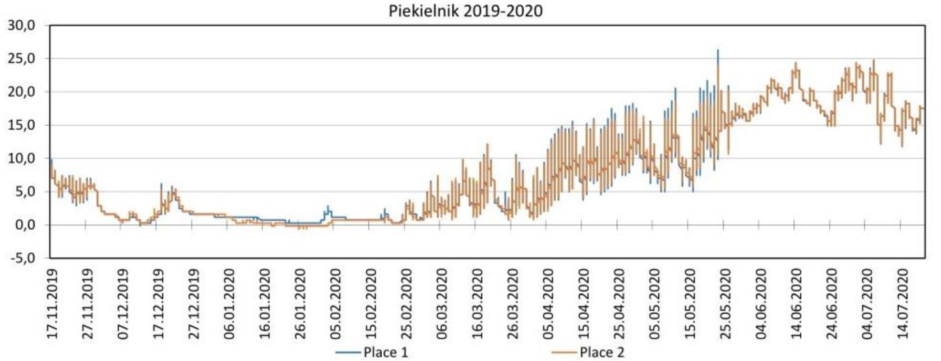


Fig. 5
Temperature distribution at the ground where the research was conducted in Piekielnik

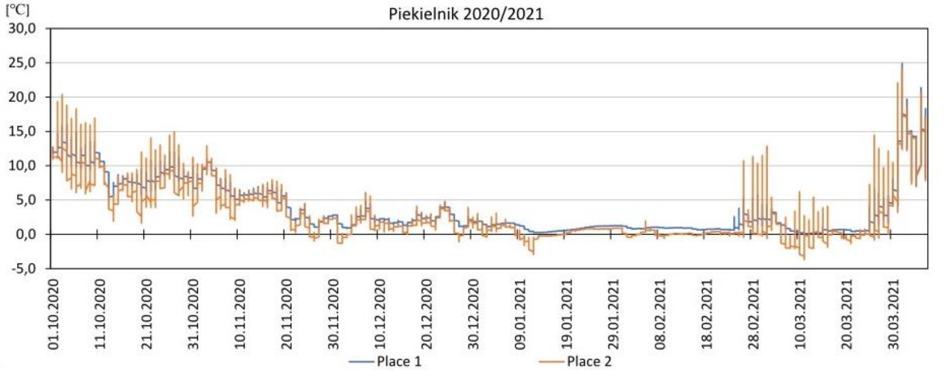


Fig. 6
Temperature distribution at the ground where the research was conducted in Piekielnik

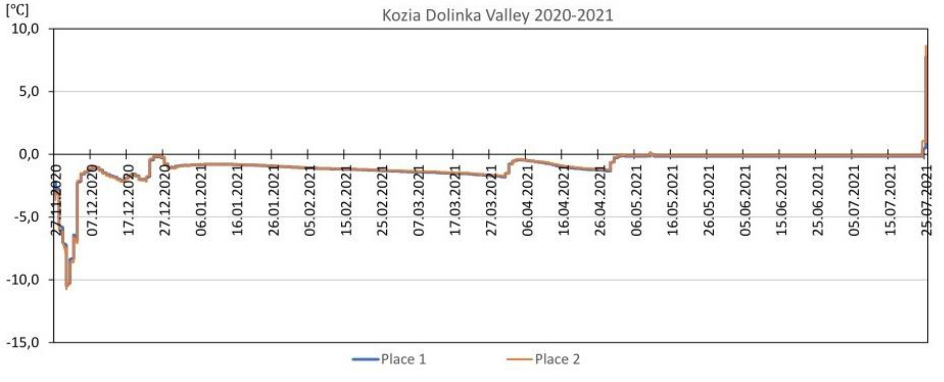


Fig. 7
Temperature distribution at the ground in the Kozia Dolinka Valley

The research results

Figure 8 presents the development of air temperature in a quinzhee shelter type, where the snow was removed from the ground. Temperature sensors were located in snow shelters after their construction, i.e. about 6 p.m. Meanwhile, one of the sensors was placed at the spruce branch. After installing the sensor in the shelter (Fig. 3a), the air temperature above the ground and under the roof oscillated within the range of about -5.0 °C up to -6.0 °C. When a given person entered the shelter and started to settle to sleep, the temperature under the roof rose to about 2.0°C while the temperature above the ground reached the value of about 0 °C. After settling in one’s sleeping bag and zipping it up, the temperature under the roof stayed at the level of about 0 °C for the whole night. On the other hand, the temperature under the ground reached the value of about -2.5 °C. At the same time, the temperature outside the shelter oscillated within the range of about -8.0÷-9.0 °C. During the whole night, the entrance was fully open. At about 9:30, the temperature value under the roof and above the ground rose again as the person got up. During the day, the entrance was fully open. Although the temperature outside equalled about -12.5 °C, in the evening the temperature inside the shelter, both under the roof and above the ground stabilised at the level of about -4,0 °C. When the person entered the shelter again and settled to sleep, the temperature rose again. During the night, the temperature under the roof dropped to about -3.0 °C, whereas above the ground it dropped to about -7.0 °C. At the same time, the outdoor temperature dropped below -20.0 °C. During the whole night the entrance was only partially covered.

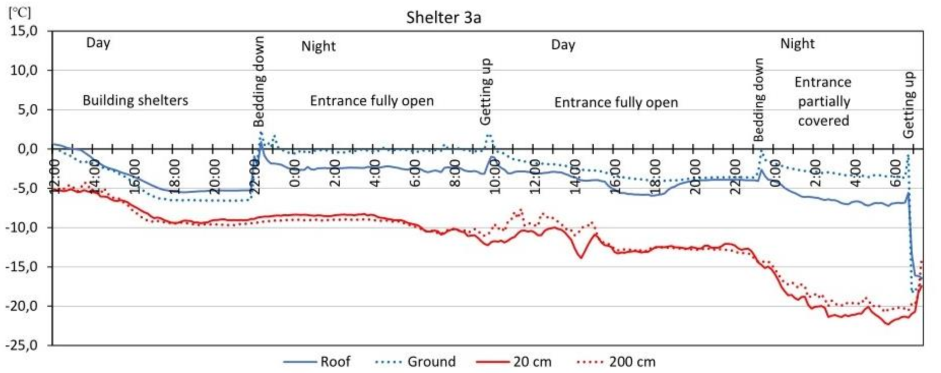


Fig. 8
Temperature distribution in shelter 3a under the roof and above the shelter's ground and outside the shelter at the height of 20 cm and 200 cm above the snow surface in the period of time of 16–18.01.2021

Figure 9 also presents a quinzhee shelter type, but with an insulating snow layer on the ground inside the shelter. Only near the entrance there was no snow cover on the ground. The hollow formed in this way was supposed to accumulate cold air. The assumed thickness of the insulating snow layer left on the ground inside the shelter was to equal about 30 cm. However, due to very powdery snow and its being pressed under the mattress, the layer was much thinner and during the second night it decreased to about 10 cm. This situation took place in all the snow shelters with an insulating snow layer on the ground. Unfortunately, the device measuring the temperature above the ground got damaged and that is why the temperature values presented in the chart come only from the sensor measuring the temperature under the shelter's roof. During the first night, the temperature under the roof, except at the moments of lying down, getting up and going to the bathroom, was positive and kept its value at the level of 0.7÷0.9 °C. During the day and most of the night, despite the person's absence and a significant decrease in outdoor temperature, the temperature under the roof dropped only to -3.7 °C. On the other hand, when the person entered the shelter, this value, similarly to the first night, went above 0 °C, i.e. up to about 0.3 °C. Despite the thin insulating layer of snow on the ground in the shelter, covering significantly a very small and low-located entrance made the temperature inside the shelter nearly 20 °C higher than outside when the person was absent. When the person was inside the shelter, the temperature stayed above 0 °C and was more than 20 °C higher than outdoor temperature.

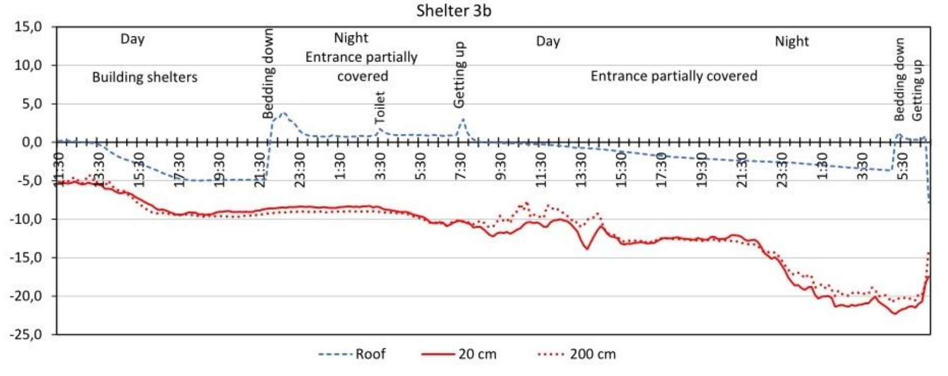


Fig. 9
Temperature distribution in shelter 3b under the roof and above the shelter's ground and outside the shelter at the height of 20 cm and 200 cm above the snow surface in the period of time of 16–18.01.2021

Figure 10 shows air temperature distribution in the quinzhee with an insulating layer of snow on the ground inside the shelter. Covering the entrance in 90% made the temperature under the roof both at the entrance and at the other end of the shelter rise during entering and getting up to over 5.0°C. On the other hand, the temperature above the ground at the entrance and at the other end of the shelter oscillated within the range of -1.7 ÷ -0.1 °C. During the day entrance covering was decreased to about 70%. In the evening, all four sensors registered the temperature of about 5.0 °C when the person was absent.

The most common mistake of people constructing snow shelters is making too big an entrance, situated high in comparison to the shelter's ground. That is why within the framework of the experiment, during the second night, the entrance was made bigger in its upper part and it was covered in about 50%. The air temperature under the roof oscillated around 0 °C, both at the entrance and at the other end of the shelter. On the other hand, in the morning the temperature above the ground dropped to about -15.0 °C at the entrance and -9.0 °C at the other end of the shelter. Taking into account the fact that a vertical distance between the sensors at the roof and the ones above the ground was about

80cm, a huge vertical temperature gradient is surprising. The difference in temperature values above the ground and under the roof was 13.0 °C at the entrance and about 7.0°C at the other end of the shelter.

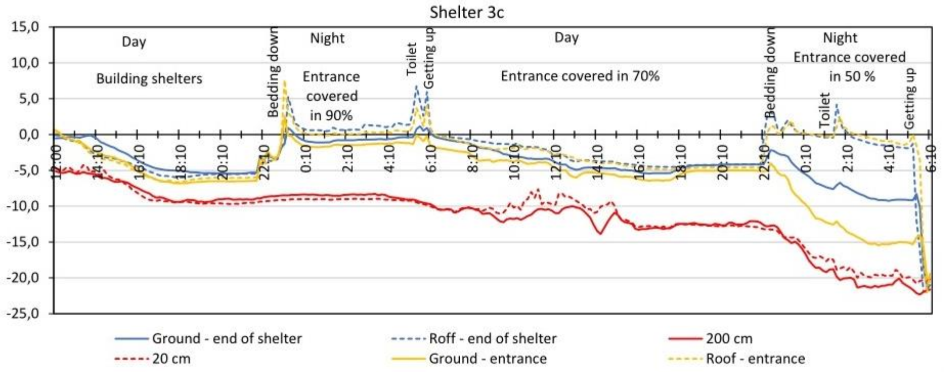


Fig. 10
Temperature distribution in shelter 3c under the roof and above the shelter's ground and outside the shelter at the height of 20 cm and 200 cm above the snow surface in the period of time of 16–18.01.2021

Figure 11 presents temperature distribution in a snow-and-plant shelter without an insulating layer of snow on the ground inside the shelter (Fig. 4a). During the first night, the temperature values both under the roof and above the ground were similar and oscillated within the range of -4.0÷-5.0 °C, except for the activities of lying down and getting up. The entrance was then covered in about 75%. During the day, with the entrance fully uncovered, the temperature under the roof and above the ground slightly decreased, especially in the evening. Our attention should be drawn to a relatively stable difference between the temperature inside and outside the shelter. During the first evening and night and during the whole next day it equalled about 5.0-6.0 °C. During the second night, when the entrance was covered in 75%, the temperature started to drop to the value of -7.5 °C under the roof and about -12.0 °C above the ground.

The next figure no 12 also shows a snow-and-plant shelter but with the catcher of cold air (Fig. 4b). During the first night, the entrance was fully covered and the temperature, except for the moment of lying down and getting up, was about -1.5 °C under the roof and about -3.0 °C above the ground. During the day the entrance was fully exposed and the temperature was systematically decreasing to reach the value of about -5.0 °C under the roof and about -7.0 °C above the ground in the evening. During the second night, the entrance was fully covered, like during the first night. As the temperature was decreasing outside, it was also decreasing inside the shelter. In the morning it reached the value of almost -5.0 °C under the roof while above the ground it dropped to about -7.5 °C.

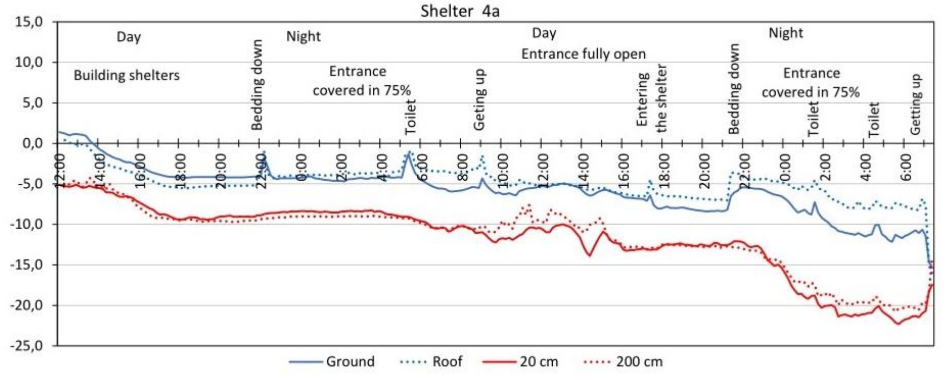


Fig. 11
Temperature distribution in shelter 4a under the roof and above the shelter's ground and outside the shelter at the height of 20 cm and 200 cm above the snow surface in the period of time of 16–18.01.2021

The next figure no 12 also shows a snow-and-plant shelter but with the catcher of cold air (Fig. 4b). During the first night, the entrance was fully covered and the temperature, except for the moment of lying down and getting up, was about -1.5 °C under the roof and about -3.0 °C above the ground. During the day the entrance was fully exposed and the temperature was systematically decreasing to reach the value of about -5.0 °C under the roof and about -7.0 °C above the ground in the evening. During the second night, the entrance was fully covered, like during the first night. As the temperature was decreasing outside, it was also decreasing inside the shelter. In the morning it reached the value of almost -5.0 °C under the roof while above the ground it dropped to about -7.5 °C.

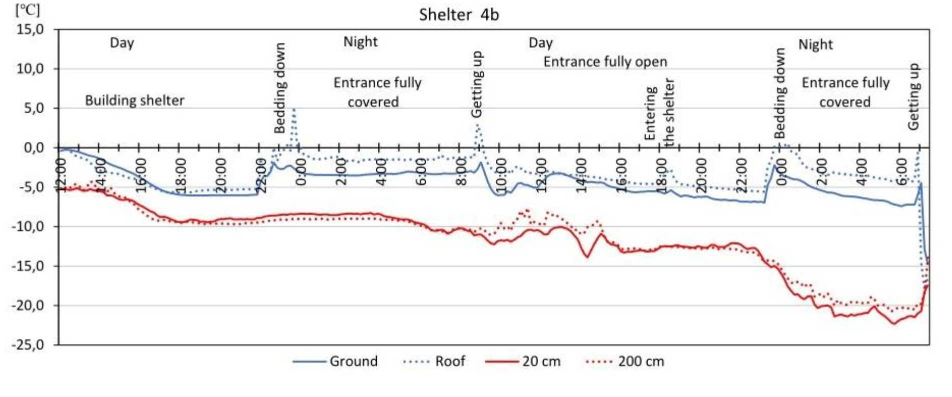


Fig. 12
Temperature distribution in shelter 4b under the roof and above the shelter's ground and outside the shelter at the height of 20 cm and 200 cm above the snow surface in the period of time of 16–18.01.2021

Figure 13 presents the last snow-and-plant shelter that was tested, also with an insulating layer of snow on the ground (Fig. 4c). Out of all snow-and-plant shelters, this one had the smallest entrance. During the first night, though the entrance was partially exposed, the temperature under the roof oscillated at 0 °C, while over the ground it was only a few tenths of °C lower. During the day, the full exposure of the entrance made the temperature drop sharply over the ground and decrease slowly under the roof. During the second night, with the entrance partially covered, the temperature under the roof oscillated at 0 °C, while over the ground it dropped to about -5.0 °C in the morning.

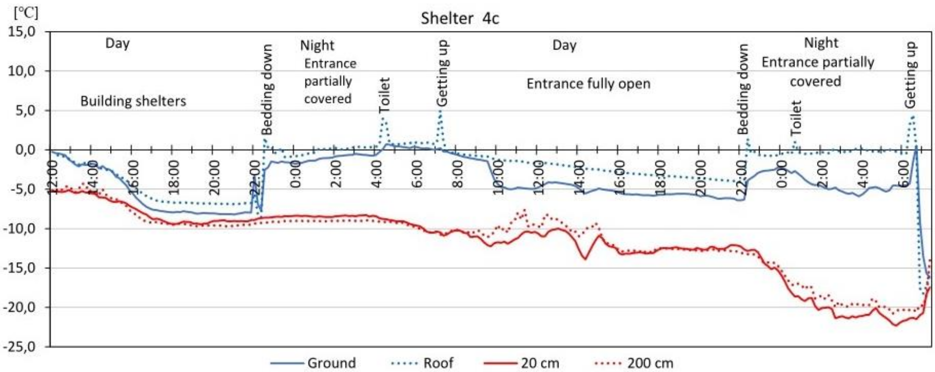


Fig. 13
Temperature distribution in shelter 4c under the roof and above the shelter's ground and outside the shelter at the height of 20 cm and 200 cm above the snow surface in the period of time of 16–18.01.2021

Self-rescue tests of the person buried in snow as a result of a collapsed snow shelter showed that wall thickness, especially the shelter's roof, should not exceed 40 cm. When the walls are thicker, getting out of the collapsed shelter might be very difficult without any help from outside, or even impossible in case of very dense snow.

The analysis of the research results

The analysis of temperature distribution in six shelters of a different design rendered very interesting results. In all quinzhee type shelters, despite the absence of a person, the temperature during the second day towards its end was higher in the shelters than outside. The difference was about 7.0 do 10.0 °C (Fig. 8–10). In the shelters with fully uncovered ground and the entrance, the temperature above the ground and under the roof dropped in the evening (about 10:00 p.m.) only to about -4.0 °C although the temperature outside dropped to about -12.5 °C (Fig. 8). On the other hand, in quinzhees with a partially covered entrance during the day and partially uncovered ground (the cold air catcher), the temperature dropped to -4.0 °C only in the morning at about 5:00 a.m. when the temperature outside reached the value below -20.0 °C (Fig. 9). Only in quinzhees with a complete insulating layer of snow on the ground the temperature in the evening dropped to about -5.0 °C in all four measurement places despite a partially covered entrance. This proves that the temperature in the shelter is strongly influenced by the heat accumulated in the ground. The more the ground is uncovered, the bigger its warming influence is.

The next very important design element having a very big impact on the temperature inside the shelter is the size of the entrance and its location. It was illustrated best during the experiment in a quinzhee with a full insulating snow layer on the ground (Fig. 10). Making the entrance bigger in its upper part during the second night and covering it in only 50% led to a significant decrease in the temperature above the ground. At the entrance it reached the value of about -15.0 °C whereas inside the shelter the temperature above the ground dropped to about -9.0 °C. Under the roof the temperature dropped to only about -2.0 °C. The entrance enlargement in its upper part also led to a huge thermal gradient. The difference in temperature values at the entrance between the roof and the ground was 13.0 °C at the height difference of about 80 cm. This proves how important it is to locate the entrance low. When it is big and dug high, the make-shift bed should be situated in the highest place possible. The analysis of three figures with quinzhees also shows that the lower in relation to the ground in the shelter the entrance is situated and the more covered it is, not only will the temperature in the shelter be higher but the difference in temperature values under the roof and above the ground will be smaller too.

In case of snow-and-plant shelters, slightly different temperature distribution was recorded. This type of shelter, contrary to quinzhees, is characterised by a slightly bigger and square entrance (Photo 3). Due to that fact, more heat escapes through the entrance than in case of quinzhees. A snow-and-plant shelter devoid of an insulating snow layer on the ground should have the highest temperature value inside. However, because of a big entrance which was covered in about 75%, the temperature in this shelter was the lowest of all shelters (Fig. 11). What is more, measurements with the help of a thermal imaging camera showed that a lot of heat escaped through the walls of this shelter as they were not thick enough, especially in their upper part. On the other hand, covering the entrance completely in the next snow-and-plant shelter with the catcher of cold air made the temperature higher than in the previously described one.

The highest temperature of all snow-and-plant shelters was recorded in the shelter with an insulating snow layer on the ground (Fig. 13). Despite the fact that the entrance was not fully covered during the night and the ground was covered with an insulating layer of snow, the temperature value during the first night, both under the roof and above the ground was high and oscillated within the range of -1.0 up to about 1.0 °C. During the second night, the temperature under the roof was still about 0 °C while the temperature above the ground dropped to about -5.0 °C. In the last snow-and-plant shelter, temperature distribution inside did not differ from temperature distribution in the quinzhees. It was because of a small entrance, walls thick enough and the roof, which was illustrated by measurements with a thermal imaging camera.

As temperature distribution graphs in figures 11–13 and measurements with a thermal imaging camera show, in case of snow-and-plant shelters special attention shall be put to the entrance size and snow wall thickness. A properly constructed snow-and-plant shelter can be as well insulated as quinzhee-type shelters. A space blanket placed at the roof of this shelter additionally protects it against dropping water from melting snow if the temperature in this shelter gets too high.

Conclusions

The results of the research conducted in the highest mountains in Poland and one of the coldest valleys in our country show that the ground temperature under the snow cover usually oscillates within the range of 0 °C to -3 °C. Such temperature values are the most suitable for the inside of snow and snow-and-plant shelters. Higher temperature values make the snow of the inside shelter layer melt and cause its faster degradation while lower values lead to excessive hypothermia of the person in the shelter.

To obtain the aforesaid temperature values in snow and snow-and-plant shelters, one should not leave an insulating layer of snow on the ground inside the shelter as it is recommended in all civil and military survival guides. The research in question showed that in the shelter without this insulating layer, the heat accumulated in the ground, despite an open entrance and lack of anyone inside, kept the temperature inside the shelter about 10 °C higher than outside. On the other hand, covering the entrance partially, when there was no one inside, increased that temperature difference to over 15 °C. Even a small ground exposure inside the shelter in form of the cold air catcher increases air temperature inside the shelter.

The size of the entrance and how high it is located have a big impact on the temperature inside snow and snow-and-plant shelters. The bigger the hole and the higher it is situated in relation to the ground, the lower temperature values and the bigger vertical thermal gradient occur inside the shelter. The conducted research shows that when the entrance was big and situated high, the difference in temperature values between the roof and the ground reached even 13.0 °C at the height difference of about 80 cm. What is more, it got too cold inside the shelter. The temperature over the ground dropped to about -15 °C. That is why the entrance should be as small as possible and it should be located at the lowest place in relation to the ground in the shelter.

The temperature in a properly designed shelter is regulated by covering the entrance. An upper (roof) air hole should be open all the time.

Obtaining the temperature values within the range of 0 °C to -3 °C in a properly designed snow and snow-and-plant shelter is possible thanks to the heat emitted by uncovered ground and the body of a person staying in the shelter. This statement is valid even when the temperature outside the shelter drops to about -20 °C. The thickness of the walls, especially the roof, should not exceed 40 cm. 30 cm thick walls provide satisfactory insulation.

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