AN INVESTIGATION OF THE THERMAL PROPERTIES OF TRADITIONAL SNOW SHELTERS

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ABSTRACT:

Traditional snow shelters have been constructed and used by Indigenous groups for centuries. Modern science has done little to quantify and compare the thermal properties of these structures. In February 1995, three snow shelters (an igloo, snow cave and quinzee) were built near the Montmorency Forest Research Station in the Laurentides, Quebec. Eight copper-constantan thermocouples were placed at intervals throughout the wall, outside and inside each snow shelter (on the floor, in the cold air trap and near the roof). During the night, temperatures were recorded using a Campbell Scientific 21X datalogger in the occupied structure. Thermal conductivities of the snow walls were calculated for each shelter. The wall of the igloo had the lowest thermal conductivity ($k = 0.27\ Wm^{-1}K^{-1}$), followed by the snow cave wall ($k = 0.36\ Wm^{-1}K^{-1}$). The quinzee wall had the highest thermal conductivity ($k = 0.56\ Wm^{-1}K^{-1}$). The results indicate that the igloo wall was the best insulator out of the three snow shelter types.

INTRODUCTION:

Snow shelters have been an important part of traditional living for several Indigenous groups in northern regions. The structural and thermal properties of snow have been effectively utilized by these peoples for centuries, providing both seasonal and emergency lodging. Modern science has done little to quantify and compare the thermal properties of these snow structures. Despite a paucity of scientific literature on this particular topic, other papers, written on the physical properties of snow as an insulator, relate snowpack thermal properties to mammalian survival. Therefore, this research paper uses information from these related studies.

Typically, freshly fallen snow has a low density (0.1 to 0.2 gcm^{-3}) and high porosity (Langham 1981). Principally, heat moves through the snowpack by conduction and is attenuated by these air spaces which have a low thermal conductivity (k: $Wm^{-1}K^{-1}$). As snow densifies, more grains come into contact with each other, thus heat is conducted more efficiently resulting in higher thermal conductivity values (Robitaille and Courtin 1990). A related property, specific heat (C: $Jm^{-3}K^{-1}$), measures the ability of a medium to retain (store) thermal energy (Oke 1987). Given these two properties, thermal diffusivity (K: m^2s^{-1})

$$K = \frac{\kappa}{C} \qquad \textbf{(1)}$$

measures the rate at which a temperature "wave" travels over a given distance through a medium (Langham 1981). Within a snowpack, water may be found in all three physical states. This complex situation may be simplified by measuring the effective thermal properties (Steppuhn 1981), which integrates the thermal interactions between these states over the whole snowpack. All thermal properties mentioned in this study refer to effective properties.

For maximum insulation, low snow density and, therefore, a low thermal conductivity is desirable. However, the inverse relationship between snow density and wall insulation is limited if the snow is to maintain its structural integrity. This relationship has important implications for the construction of snow shelters. Previous studies have shown that an increase in snow density results in an increase in thermal conductivity (Langham 1981; Kalliomaki *et. al.* 1984). In addition, snow density is positively correlated with the bearing strength of the pack (Gould 1956). The very nature of igloos and snow caves require that they are built using dense snow (Steltzer 1981). In contrast, a quinzee, another type of shelter, is constructed using a mixture of snow, including fresh snow with its low density. This snow is left in a conical pile to sinter, which increases its density (Marchand 1987). After sintering, the quinzee is excavated; the insulative qualities of the original snowpack having been substituted for the higher bearing strength of the shelter's roof.

The present research seeks to quantify the thermal properties of three types of snow shelter walls: igloo, snow cave and quinzee. The comparison of these results will aid in our understanding of the various insulative advantages and shortcomings of these shelters.

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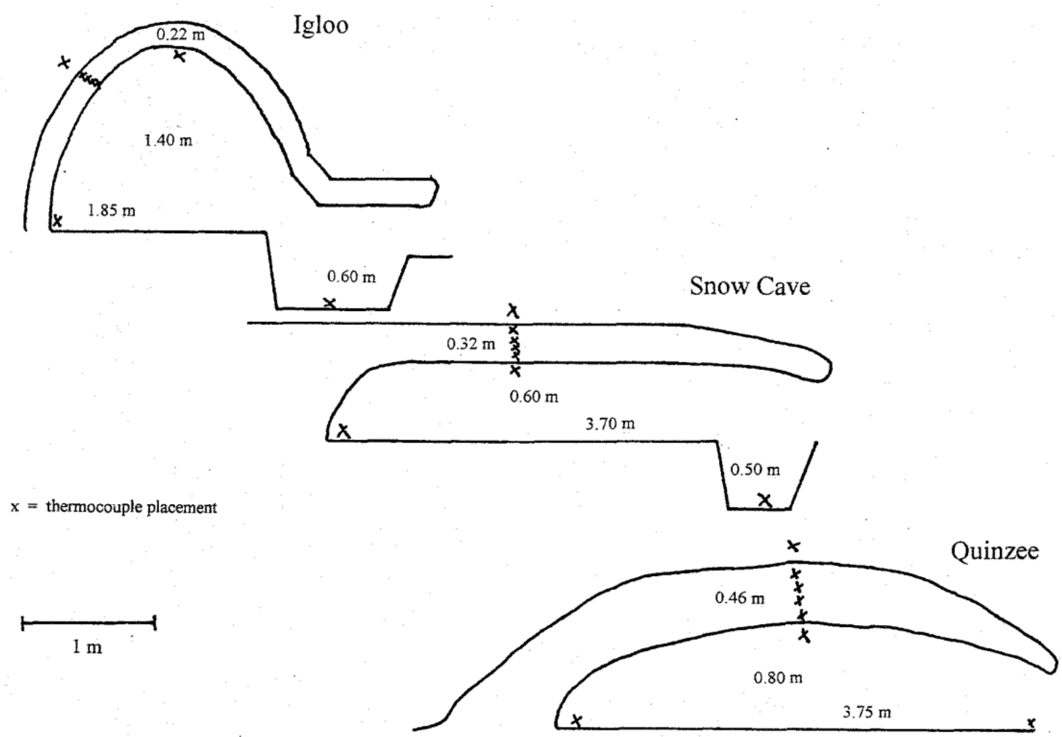
METHODS:

An igloo, snow cave and quinzee were constructed near the Montmorency Forest Research Station in the Laurentides, Quebec. Hard packed snow, suitable for the construction of an igloo was located in a snow bank adjacent to a parking lot. This same snow was also used to make the snow cave. Fresh snow needed for quinzee building was piled up and allowed to sinter overnight. A cold air trap was dug at the entrance of both the igloo and the snow cave, allowing colder air to "pool" lower than the sleeping platform (Figure 1). A cold trap was not constructed for the quinzee because of the insufficient height of the sintered snow pile. After construction, each of these shelters was occupied for one night; by two people for the igloo and cave, and by one person for the quinzee. Occupancy provides a heat gradient between the interior and the exterior, facilitating the measurement of thermal properties.

Figure 1. Snow Shelter Dimensions



Temperature was measured by eight copper-constantan thermocouples placed throughout the wall and inside each snow shelter. One thermocouple was placed on the exterior of the wall, four were spaced evenly across the wall, and the remaining thermocouples measured temperatures near the floor and roof of the shelter, and at the bottom of the cold trap. A Campbell Scientific 21X data logger scanned temperatures every five seconds and recorded averages of these readings at twenty minute intervals. Data was collected both before and after occupancy of the shelter.

Thermal diffusivity was calculated using a derived version of Monteith's equation (1973):

$$\frac{\delta T}{\delta t} = K \frac{\delta^2 T}{\delta z^2} \qquad (2)$$

$$K = \frac{z^2}{t} \qquad (3)$$

particular temperature to travel a distance z (m). "z" was measured as the distance between adjacent thermocouples. "t" was determined as the time required for the temperature at adjacent thermocouples to become equal. Temperatures were considered to be "equal" if they differed less than 0.02°C. However, the temperature trend (hot to cold or cold to hot) had to be the same in both thermocouples for a temperature wave to be analyzed (temperature waves beginning either inside or outside the shelter were used). Thermal diffusivity data were averaged for each snow shelter so that thermal conductivity could be calculated. Data from the thermocouple located 2cm within the wall of the quinzee and exterior temperature measurements during the snow cave study were rejected due to accidental disconnection of these thermocouples. Exterior temperature data were substituted with measurements taken from a nearby thermograph.

The specific heat of each shelter wall was calculated by multiplying the specific heat of pure ice by the mean wall density and dividing by the density of pure ice. Thermal conductivity was calculated by multiplying the specific heat and the mean thermal diffusivity (Equation 1).

RESULTS:

The mean nocturnal exterior and interior temperatures for each snow shelter are summarized in Table 1. The mean exterior temperature was coldest during the night of the igloo study (-17.22°C), followed by the snow cave study (-13.82°C) and lastly the quinzee study (-7.17°C). The mean interior roof temperature was highest in the igloo, followed by the quinzee and snow cave (Table 1). Mean floor temperature was highest in the quinzee followed by the igloo and finally the snow cave (Table 1). The cold air traps in the igloo and snow cave show much colder temperatures (-11.40°C and -11.92°C respectively) than the floor at the entrance of the quinzee (-5.87°C).

Mean Nocturnal Temperatures (°C)

1:20am-7:20am

	Igloo	Snow Cave	Quinzee
Exterior	-17.22	-13.82	-7.17
Roof	-1.30	-5.29	-1.62
Floor	-4.90	-8.25	-3.24
Cold Trap	-11.40	-11.92	-5.87*

*** This thermocouple was placed on the floor near the entrance**

Figure 2 shows the mean nocturnal temperature profile of the snow shelter walls. The regressions of distance versus temperature show a high R^2 for both the igloo ($R^2 = 0.96$) and the snow cave ($R^2 = 0.97$) and a lower R^2 for the quinzee ($R^2 = 0.81$). Figure 3 summarizes the measured physical and thermal properties of snow shelter walls. The igloo and the quinzee are approximately equal in both density and specific heat (n=4) Figure 3). The snow cave shows a higher value for both these measurements (Figure 3). Trends in thermal diffusivity and the derived thermal conductivity are similar. The igloo shows the lowest thermal diffusivity and conductivity followed by the snow cave and lastly, the quinzee (Figure 3).

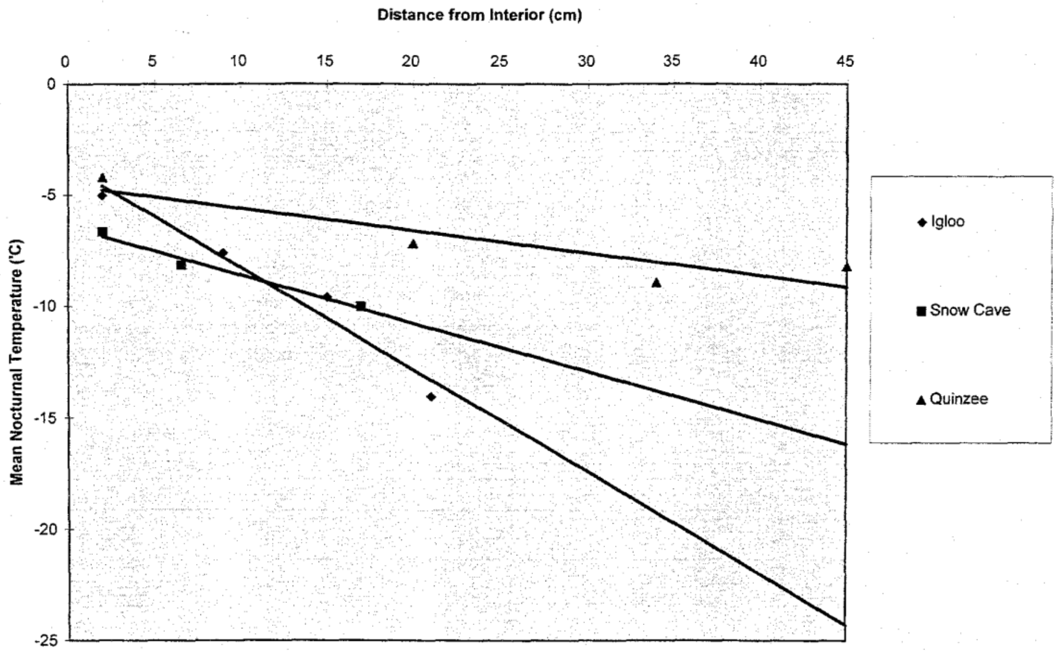


Figure 2. Thermal Cross Section of Snow Shelter Walls

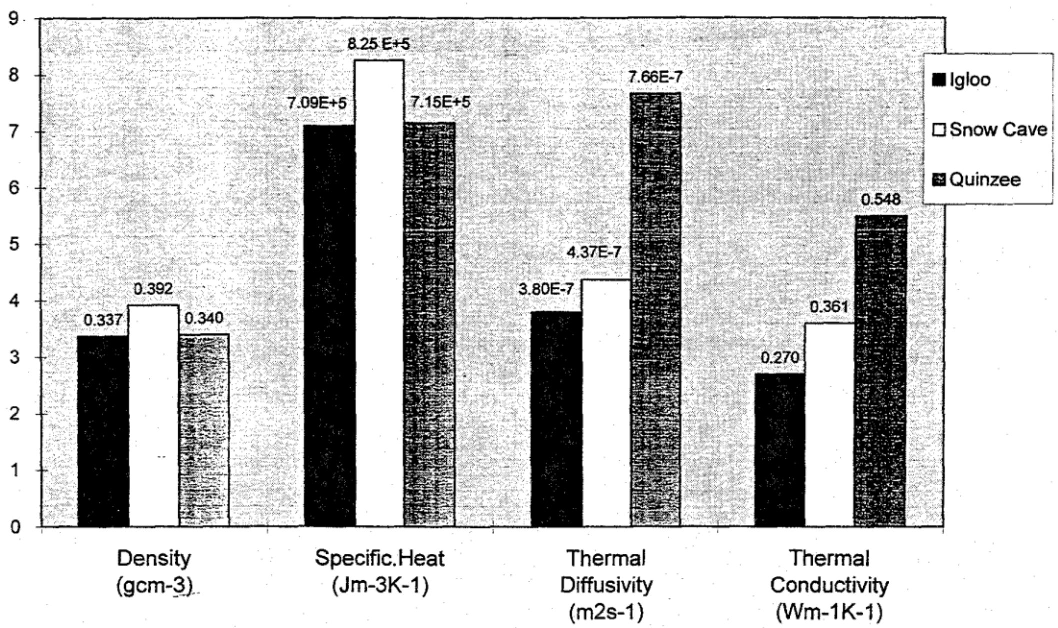


Figure 3. Thermal and Physical Properties of Snow Shelter Walls

DISCUSSION:

In terms of the relative differences between interior and exterior air temperatures, it would seem that the igloo is the most insulated of the three snow dwellings. While the igloo shows the highest gradient between interior and exterior temperature, this gradient is not as pronounced in the quinzee data. This is probably because of the exterior temperature being low during the igloo study whereas, the exterior temperature is warmer during the snow cave and quinzee studies. Also, warm air would tend to collect at the top of the igloo, concentrated there by the "domed" shape, thereby favouring the results of the igloo. The difference in temperature between the interior and exterior of an occupied snow shelter is typically smaller that the exterior temperature. Therefore, analysis of quinzee data should reflect the larger proportion of heat that is used up by melting ice instead of heating the air. This effect is more pronounced as the temperature approaches 0°C. A cross section of snow shelter walls is useful in determining the homogeneity of thermal properties (Figure 2). The R^2 value is a measure of the heterogeneity of the wall's thermal (and physical) properties. High R^2 values represent a consistent gradient. Lower R^2 values denote more variability in snow properties and therefore a high degree of snow type mixing within the walls. It is not surprising to note that the R^2 value for the quinzee was lower than both the igloo and the snow cave. This likely reflects the incomplete sintering of the quinzee walls, giving a variation in thermal properties across the wall.

The physical properties of snow shelters (i.e. density), along with snow crystal structure and texture (Arons and Colbeck 1995) control the thermal properties of the walls. The difference between the density trend and the trend in thermal diffusivity and conductivity suggests that there is a different crystal structure in the quinzee vis a vis the igloo and snow cave. Thermal conductivity is a measure of insulation quality, whereas the wall thickness shows the insulation quantity. The igloo has the highest insulation quality, but also has the lowest insulation quantity. Because there was no controlled exterior temperature in this study, no comparison between snow shelters can simultaneously take both the insulation quality and quantity into account.

SUMMARY:

In conclusion, the results of this study show that, in terms of insulative quality, igloos ranked first, followed by snow caves and then quinzees. Further investigation is required to assess the reasons behind these differences. A controlled situation, where all three types of snow shelters are occupied and monitored during the same time periods is necessary for direct comparisons. Other studies could focus on the change of snow crystalline structures and effects of insulative properties during snow metamorphosis.

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