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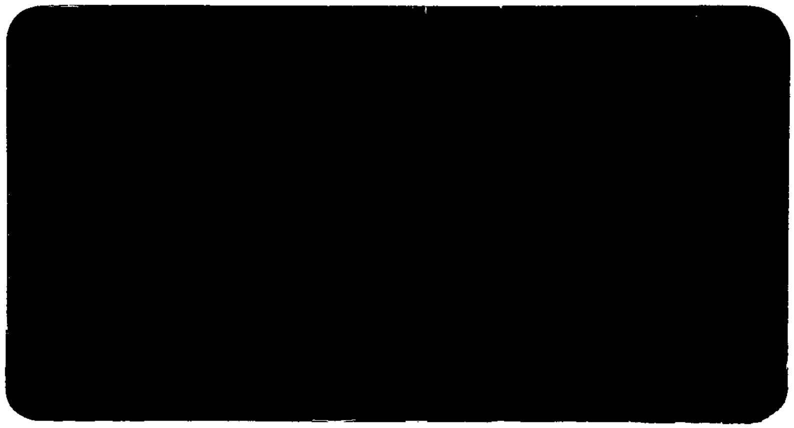

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THERMAL RESISTANCE OF THE CHEEK IN COLD AIR

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Abstract

Some experiments were carried out to characterize the thermal resistance of the tissues of the cheek area. Heat flow and skin temperature in cold air were measured with a heat-flux transducer. The face was uncomfortably cold when the cheek skin temperature was below 15°C and painful when the skin temperature fell below 10°C. Thermal resistance increased as skin temperature fell, reaching a maximum value of 0.07 m^2K/W at a skin temperature between 10 °C and 15 °C.

Introduction

The temperature of the skin of the face is a key factor in overall thermal comfort. Some of the body's most important thermal control mechanisms seem to be actuated or modified by the effects of the weather on the naked face (1,2). The nose, chin and cheeks are the coldest parts of the face in cold air (3). In cold winds, Stroud (4) found that the chin or the cheek was usually the coldest area. LeBlanc et al. (5) found that the cheek cooled more quickly than any other part of the face, however, the nose seems to be more susceptible to frostbite (6).

The temperature of the skin depends not only on the transfer of heat from it to the atmosphere, but on the transfer of heat to the skin from deeper tissues. Some experiments were carried out to characterize the thermal resistance of the tissues of the cheek area.

A preliminary study in 1987, which involved four male subjects aged 20 to 36 years, indicated that the thermal resistance of tissues in the cheek area increased as skin temperature fell. One of these subjects (Subject A) was examined at a greater range of skin temperatures than the others and was re-examined six years later, using similar methods. Only one, highly motivated, subject was re-examined because low temperatures caused significant and sustained discomfort.

Method

Heat flow and skin temperature were measured with a heat-flux transducer (RdF 20455-3), which contained a thermocouple. The heat flux transducer calibration was checked on a guarded hot plate at several temperatures. The electrical potentials generated by the sensor and thermocouple were measured by two Fluke 45 digital multimeters, which are capable of measuring a DC potential difference as low as one microvolt. The differential thermocouple produced a signal of approximately 40 microvolts when the temperature difference was one degree Celsius. As the heat-flux sensors have calibration constants of almost 2 W/m^2 per microvolt, a heat transfer rate of 100 W/m^2 produced as signal of over 50 microvolts. The heat flux transducer measured 1.9 cm by 3.6 cm and was almost paper thin. As in the preliminary study, it was affixed horizontally to the skin of the cheek with Blenderm tape, 3 cm below the centre of the left eye.

To determine the thermal resistance of the tissues of the cheek, the heat flux and skin-to-core temperature gradient were required. To measure the difference between the skin temperature and the internal body temperature, the thermocouple reference junction was placed under the subject's tongue until a steady state had been reached. The reference junction was then removed, dried and placed it in the air 15 cm in front of the face, next to the bulb of a mercury-in-glass thermometer to measure the skin-to-air temperature difference. Both were shielded from direct radiation from the face. The thermometer had been calibrated at 0 °C and was capable of measuring the air temperature to 0.1 °C.

The thermal resistance of the tissues of the cheek was determined from the ratio of the heat flux to the skin-to-internal temperature difference. The skin temperature was found by adding the skin-to-air temperature difference to the air temperature.

The subject sat on a stool with his upper body inside an insulated enclosure. The air temperature in the enclosure was controlled to 0.1 °C, and was varied between -30 °C and 33 °C. The enclosure was a temporary antechamber attached to a Thermotron S-8 environmental chamber. It was insulated with 5 cm of extruded styrofoam building insulation. Although the air temperature was controlled to ±0.1 °C, turbulence caused the skin temperature and heat flux to vary about a mean value even after an approximate steady state had been reached. The mean value was determined by averaging over a period of about five minutes.

A thin dividing wall of air permeable fabric separated the antechamber from the main chamber. The fabric greatly reduced the wind speed and turbulence in the antechamber and shielded the face from direct exchange of thermal radiation with the cold surface of the heat exchange unit in the main part of the chamber. The temperatures of the inner surfaces of the antechamber were within a few degrees of the air temperature.

Because the rate of air movement in the chamber varied with location, the subject's head could not move during the experiment. It rested against blocks of rigid foam in one corner of the chamber. The subject did not speak and tried not to use his facial muscles during the exposure. Exposures lasted a minimum of forty minutes in mild temperatures and at least seventy-five minutes at the lowest temperatures.

Results

Tissue resistances at various cheek temperatures are presented in Figure 1. The values in Figure 1 are averages over a period of about five minutes at the end of each exposure.

The apparent thermal resistance of the cheek increased with a decrease in skin temperature and reached a maximum value of about 0.07 m^2K/W

when the skin temperature was between 10 °C and 15 °C. On inspection of the graph, the variation of thermal resistance at skin temperatures greater than 15 °C appears to be less than ± 0.01 m^2 K/W. Greater variation is apparent at lower skin temperatures. There was no apparent change in the thermal resistance of the cheek of the more intensively studied subject over the period of six years.

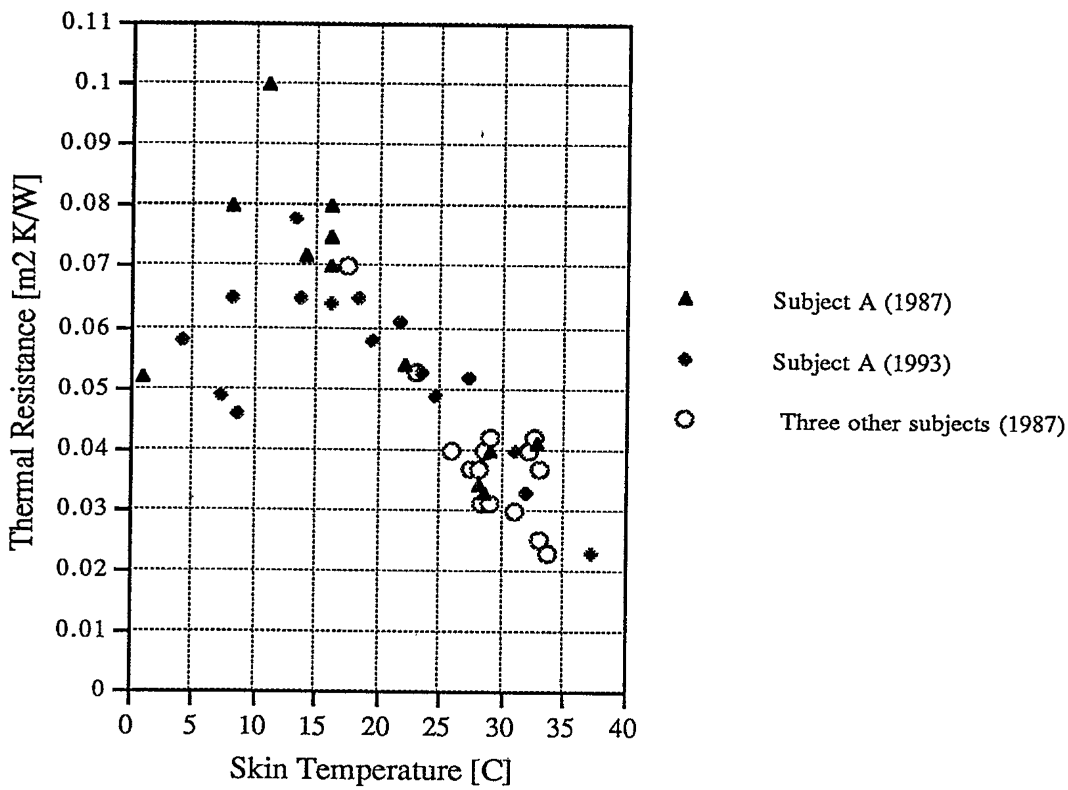

Fig. 1. Thermal resistance of the cheek.

Discussion and Conclusions

The number of subjects was small, and was limited to a single subject at the lowest skin temperatures. However, the results are consistent with the observations of others. The face was uncomfortably cold when the cheek temperature was below 15 °C and painful when the skin temperature fell below 10 °C. LeBlanc et al (5) observed a similar sharp decrease in comfort when the temperature of facial skin dropped below 15 °C.

The maximum value of cheek thermal resistance is close to the 0.068 m^2K/W for the whole head, obtained by Froese and Burton (7). They did not notice any variation in thermal resistance with temperature, however the cheeks are such a small part of the total area of the head that they might not have been able to detect changes in their thermal resistance.

The scatter in the data below 10 °C may be due to vasodilation induced by the cold. As the cold skin was sometimes intensely irritating, the stress may have increased the metabolic rate. The temperature of the skin of the cheek, has been observed to be higher at higher metabolic rates (8). The thermal resistance of the cheek of an active individual is therefore probably lower. This information will be useful in predicting frostbite and in modelling heat transfer from the face in cold winds.

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