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Fabric Heat Transfer by Conduction and Radiation

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Abstract

Persons exposed to solar heat radiation in hot and dry climates are at increased risk of heat illnesses. Clothing can reduce such exposure. The effectiveness of clothing to reduce such heat loading depends on the ability of the fabric to reflect this heat radiation. However, incomplete reflection results in fabric heating which will heat the body by conduction. The protection against heat radiation by a garment can be offset by the retention of metabolic heat due to insulation. This will counteract the IR attenuation benefits offered by the clothing. An accurate understanding of such a trade-off is needed in order to optimize the selection of clothing when managing heat stress resulting from exposure to solar IR heat radiation. Laboratory experiments were performed on multiple layers of Cotton, Nylon, Wool and Polyester fabric to evaluate their heat insulation characteristics and IR heat attenuation properties. The relationship between fabric layers and IR attenuation properties was examined under controlled laboratory conditions. The results of this study showed that fabric insulation heat gain and corresponding IR radiation attenuation was proportional to the number of fabric layers used. However, the IR heat radiation attenuation was significantly greater with each additional fabric layer than the heat gain penalty associated with fabric insulation. Additionally, heat transfer by condition was seen to contribute about 18% of the radiant heat transfer to the body. Separating the fabric from the body using a spacer will reduce this amount of heat transfer to the skin. The results of this study show that multiple fabric layers can significantly reduce the risk of IR heat radiation overexposure while limiting the metabolic heat build-up inside protective clothing. The study also confirms that by selecting the appropriate number of fabric layers, it is possible to optimize the IR heat radiation protection while limiting metabolic heat build-up inside clothing.

Keywords: Solar Heat Stress; IR Heat Radiation Attenuation; Multi-layered Clothing; Fabric Insulation, Heat Transfer by Conduction

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1 Introduction

Workers exposed to outdoor solar heat radiation are at increased risk of suffering heat related disorders [1-3]. Use of tents, hats, and other protective equipment are frequently used to reduce such exposures. However, these measures are often impractical when employees must change postures or are required to move to new locations. Innovative use of clothing materials and creative approaches to garment design can help reduce clothing heat stress during exposure to outdoor solar environments [4-5].

While clothing can offer a barrier to solar heat radiation, protective garments can also lead to physiological heat stress by limiting the dissipation of body metabolic heat [5-8]. The goal of this study is to identify the cost - benefit of multiple garment fabric layers that balance garment insulation with garment heat radiation attenuation. To pursue this objective, experiments were conducted to evaluate the heat insulation characteristics and the associated IR heat radiation attenuation properties of four different fabric types.

In evaluating clothing induced heat stress, it must be recognized that the human body is a heat producing system that attempts to maintain a balance between heat gain and heat loss. Environmental parameters such as air temperature, air velocity, radiant heat, and humidity can all affect this balance. Clothing material and garment design can influence this heat balance also by promoting or reducing heat exchange via sweat evaporation, convection, conduction, and heat radiation [9-10]. The specific performance during heat radiation exposure can also be linked to the chemical and physical structure of the garment materials itself including thickness and weight [11-16].

Previous research evaluating the impact of heat radiation on protective clothing has shown that fabric thickness is an important factor affecting the IR protective performance of a garment [17-18]. Additionally, these studies have shown that a multi-layer system can provide high levels of protection [19, 20].

2 Methods and Procedures

2.1 Fabric Samples

Four fabric types were evaluated that included six samples of Wool (100%), Nylon (100%), Cotton (100%) and Polyester (88%). Insulation characteristics and IR radiation attenuation properties were evaluated for 1, 2, 4, and 6 layer combinations. Each fabric sample was 10 cm×10 cm in size. The Wool sample had a thickness of 1.0 mm and weighed 2.0 grams, the Nylon sample

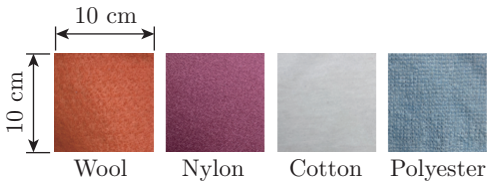

Fig. 1: Wool, Nylon, Cotton and Polyester fabric samples evaluated in the study. Each sample was 10 cm × 10 cm in size. Insulation characteristics and IR radiation attenuation properties were evaluated for 1, 2, 4, and 6 layer combinations