Assessment of an active liquid cooling garment intended for use in a hot environment

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Abstract

This paper discusses the construction of a designed active liquid cooling garment (LCG) that has been developed in order to reduce thermal discomfort of persons working in hot environments. It consists of clothing with a tube system distributing a cooling liquid, a sensor measuring the microclimate under the clothing, and a portable cooling unit with a module controlling the temperature of the cooling liquid depending on the microclimate temperature under the clothing. The LCG was validated through tests on volunteers in a climatic chamber at 30°C, a relative humidity of 40%, and an air movement rate of 0.4 m/s. The obtained test results confirmed the beneficial effects of the cooling system used on mean weighted skin temperature, the physical parameters of the microclimate under the clothing, and the participants' subjective assessments, as well as confirmed that the functioning of the control system regulating liquid temperature in the LCG was correct.

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1. Introduction

In Poland about 18 thousands people work in hot environments (at air temperatures ranging from 25 °C to 60 °C and a relative humidity of 10%–80%), for instance in metallurgy, the glass industry, mining, and also in a number of outdoor jobs during heat waves in the summertime (Central Statistical Office, 2015). Additionally, workers in hot environments are often exposed to hazards such as molten metal splashes or contact with other hot objects. In order to remove the hazards resulting from long-term worker exposure to hot environments, it is necessary to eliminate or reduce heat accumulation in the body. In extreme environmental conditions, active cooling may be the only viable option for reducing the heat strain (Selkirk et al., 2004). Unfortunately, in some workplaces it is impossible to install air-conditioning systems due to the technological processes used or large spaces. In the absence of any other possibilities to cool workers, it may be a good solution to apply individual cooling systems. Therefore, efforts are being made to design efficient individual cooling systems that would make it possible to dissipate the excess heat generated by one's body during work (Furtado et al., 2007).

The choice of a personal body cooling system to be used under protective clothing in a hot environment should be based on the choice of an appropriate cooling medium: ice (Smolander et al., 2004), water and air (Vallerand et al., 1991) or phase change materials (Bartkowiak et al., 2013). Such a system should be adjusted to the working conditions at a given workplace, taking into account the weight, mobility restrictions, cooling power, etc., of the system. All the above-mentioned media can be used as an effective solution for dissipating excess heat from the human body provided that the potential application of the system is taken into account in the design process. Ice cooling systems surpasses the others in terms of the effectiveness of dissipating excess heat by conduction and radiation. In turn, air cooling systems are the most effective in removing heat by convection and evaporation (Caldwell, 2008); however, their performance depends to a great extent on the physical parameters of the air and the properties of the protective clothing used. Liquid cooling systems are characterized by a higher level of heat reduction than air cooling systems because water has higher thermal conductivity than air, and thus are recommended for cooling workers who work in hot environments in impermeable protective clothing preventing sweat evaporation (Sakar and Kothari, 2014). In contrast to cooling systems with solid coolants (such as ice packs, phase change materials, gel packs, etc.), liquid cooling systems can be given a desirable shape that does not restrict the wearer's movements and does not limit the fit of the garment to the body. Moreover, they do not result in frequent donning and doffing of protective clothing to exchange coolant
Figure 1. A view of a profile of the spacer module showing channels for the tubes distributing a cooling liquid.
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