Effectiveness of Electrical Heating for Improved Thermal Insulation of a Multi-layered Winter Clothing System

Huiju Park, Cornell University, USA
Soo-Kyung Hwang, Seoul National University, Korea
Joo-Young Lee, Seoul National University, Korea
Jintu Fan, Cornell University, USA
Youngjin Jeong, Soongsil University, Korea

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Thermal protection against cold environments is a major function of clothing, not only for those who work in low temperature conditions with high risk of cold injuries, but also for people who enjoy outdoor activities during the winter. Clothing made of materials having high thermal insulation is essential for thermal protection, but it typically entails an increased bulkiness of the clothing which significantly limits human performance (Wang, Gao, Kuklane, and Holmér, 2010), and even introduces discomfort and fatigue due to the increased physical strains over time while moving in heavy and bulky garments (Goldman and Kampmann, 2007). In this sense, electrically heated garments could be a solution because they provide extra heat which can reduce the bulkiness associated with conventional winter clothing materials. While a majority of previous studies investigated input heating power aimed at increasing the temperature of the heating units, few studies were found that investigated the heating efficiency of the electrical heating, particularly in a multi-layered winter clothing system. The distance from the heating unit to the body can play a key role in potential heat loss due to a cold environment and in heat transfer in a multi-layered structure to the body at different levels of ambient temperature. Therefore, this study investigated the impact of the distance of the heating unit from the body in a multi-layered winter clothing system on thermal insulation and heating efficiency, using a thermal manikin at two different ambient temperature conditions (-5°C, and 10°C, 37% RH, air velocity < 0.1 m/s).

To identify changes in the thermal insulation and heating efficiency of electrical heating, a multi-layered winter ensemble with and without activation of a heating unit was tested on the thermal manikin. The configuration of the garments for the testing ensemble included four layers

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of items (short sleeve undershirt, long sleeve shirt, vest and winter jacket) on the upper body, long pants, socks, and footwear on the lower body. The heating unit consisted of four heating panels (10cm x 15cm), which were placed on the chest and back of the testing layer of the ensemble. The surface temperature of the heating unit was maintained at 38 (±1) °C during the testing. The heating unit was operated by a lithium-ion battery (7V and 2.2 Ah). The skin temperatures of the 20 zones of the thermal manikin were all set at 33.0 °C. First, the thermal manikin test was conducted without the activation of the heating unit. Then the heating unit was placed on the inside of the first layer (short sleeve undershirt) of the ensemble, and then the thermal manikin test was conducted while the heating unit was activated. This process was repeated to identify changes in the effective thermal insulation of the ensemble and heating efficiency depending on the location of the heating unit. Thermal manikin test was repeated three times in each test condition.

For the data analysis, the effective thermal insulation and power consumption (watts) were measured. Heating efficiency was also evaluated by comparing decrease in power consumption with electrical heating. The results of this study indicate that providing electric heating next to the skin is the most effective in increasing effective thermal insulation and decreasing body heat loss in cold environment. This trend was more remarkable in colder environment at -5°C of ambient temperature as evidenced by sharp decrease in heating efficiency and effective thermal insulation with an increase in distance between the manikin skin and heating unit at -5°C of ambient temperature. Thus, it is expected that proximity heating next to the skin, in cold environment, may reduce the weight and size of the battery for the heating unit because of the higher efficiency of electric heating and the potentially immediate perception of warmth supported by the greatest increase in effective thermal insulation, as well as the lowest heat loss that comes with activation of heating on the first layer in cold environment. This study found that effective thermal insulation of testing ensemble increased by 5% and 7% in 10°C and -5°C ambient temperature conditions, respectively, when the heating unit was placed on the first layer of ensemble on top of manikin skin. This study measured only dry thermal insulation. Future studies should consider the impact of moisture inside the clothing system on the change in thermal dynamics in the microclimate and on the wearer's perception of comfort in a cold environment, investigating the thermal insulation and evaporative resistance, with simulation of human perspiration and body movement.

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