Predicting Thermal Functional Performance of Protective Clothing Through Computer Simulations

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Abstract: Previous simulations associated with the heat and moisture transfer behaviors of clothing are mainly expressed with mathematical models, relevant computational algorithms and numerical solution methods and thus accessible to only a few professionals in the field. A software platform, called the S-smart system, was designed and developed as a friendly computer aided design tool with user friendly interfaces for users with little/limited background knowledge of technical information, complex physics, mathematics and computational techniques. The purpose of this study is to report a simulation test, using the S-smart system, for predicting the thermal functional performance of personal protective clothing. The results pertaining to skin temperature, core temperature and humidity in the clothing microclimate between the chest wall and underwear were compared with experimental data. Good agreement, both in terms of the trends of changes and overall mean values, is observed between the two. Furthermore, 2D and 3D visualizations of the S-smart system seemed to provide more evidence that explains the heat and moisture transfer mechanisms and predicts thermal functional performance of clothing.

Keywords: computer simulation, S-smart system, personal protective clothing, thermal functions

1. Introduction

Personal protective clothing (PPC) is required in many contexts such as hospitals that provide a range of barrier protection against blood, body fluids and viral threats in order to help maintain the sterile zone for both staff and patient safety. However, like other clothing, PPC, as an interactive barrier, could affect the heat loss efficiency. Clothing entraps air next to the skin in the weave of the cloth, thereby increasing the thickness of the so-called private zone of air adjacent to the skin and also decreasing the flow of convection air currents. Consequently, the rate of heat loss from the body by conduction and convection is depressed [1], and heat balance is affected. Under normal or stationary conditions, the human body produces little perspiration or saturated water vapor, and the wearer does not experience any significant discomfort while wearing either a cotton or polyester shirt [2]. Problems arise when active exercise, such as running for saving the patients from life threatening situations or moving the patients in hospital, causes sweating and evaporation. The garments in the clothing ensemble will reduce the dissipation of moisture, which may lead to sweat accumulation in garments during work and therefore result in the generation of heat stress. Clearly, there is a need to investigate the heat and moisture transfer behaviors of PPC in order to understand PPC comfort performance.

Traditionally, the comfort performance associated with the heat and moisture transfer behaviors of clothing is evaluated by subjective wearer trials. However, the subjective wearer trials may fail to simulate the practical environmental conditions accurately, which might lead to the inconsistent results. On the other hand, the costs of some subjective wearer trials are high not only in terms of the required environmental simulation, and clothing but also because the subjects have to be paid to participate. Therefore, the objective simulation tests are developed as a more acceptable option. The mathematical modeling and numerical simulation of the heat and moisture transfer in clothing materials

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and the human body have been extensively reported [3-10]. More recently, a mathematical model to describe the complicated and coupled physical mechanisms concerning the heat and mass transfer in vivo worn facemasks during breathing cycles has been developed [11]. With this model, the theoretical predictions are compared with experimental data of in-vivo protective performance of facemasks [22], and good agreement is observed between the two, indicating that the model is satisfactory. However, these simulations are mainly expressed using mathematical models, relevant computational algorithms and numerical solution methods, which limits the use of the model to a few professionals in the field.

Keeping in mind that the simulations need to be undertaken by the common designers, engineers and researchers with little/limited background knowledge of the technical information, complex physics, mathematics and computational techniques, Li et al. designed and developed a software platform, called the P-smart system, as a friendly computer aided design (CAD) tool with user friendly interfaces [12]. Li et al reported the design and development of this new CAD system and simulated thermal behavior when wearing the hydrophilic and hydrophobic sportswear. They compared the simulation results with the experimental measurements on the skin temperature, core temperature and the temperature at the inner surface of clothing, and concluded that the P-smart system is able to provide reasonably good simulation results that fit closely with the experimental observations. However, the comparison did not include the humidity in the clothing microclimate between the chest wall and underwear. On the basis of the P-smart system, Mao et al. designed and developed an improved software platform, called the S-smart system, which is also a CAD tool with user friendly interfaces [13]. Neither the P-smart system nor the S-smart system has been used by the common users as yet. The purpose of this paper is to report a simulation test performed by common researchers for predicting the thermal functional performance of PPC using the S-smart system. The results of the skin temperature, core temperature and the humidity in the clothing microclimate between the chest wall and underwear are compared with experimental data.

2. Methods

In order to investigate the prediction ability of S-smart, we compare the predictions from the S-smart with the experimental observations reported elsewhere by Guo et al [14].

2.1 Wear Trial

A wear trial was conducted by asking ten human subjects to wear PPC. Profiles of the subjects are 22.4 ± 0.55 years of age, 171.8 ± 3.42 cm height, 61.08 ± 4.72 kg body mass. 1.68 ± 0.08 m^2 body surface area. In the trial, two types of PPC ensembles were used as experimental clothing:

PPC1: 100% polyethylene barrierman, a commercially available pure cotton surgical scrub suit worn inside barrierman, an N95 respirator (3M 1860) (3M Canada Company) and a disposable face shield. This ensemble is commercially available in Hong Kong.

PPC2: a waterproof breathable protective gown with a head cover, a surgical scrub suit worn inside the gown, and a respirator with exhaust valves and ventilation pipes. This ensemble is custom designed by the Hong Kong Polytechnic University. Two ensembles used in the experiment are illustrated in Figure 1

PCC1 PCC2

Figure 1 Two different types of personal protective clothing ensembles used in wear experiment