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Development and Application of Thermoregulatory Manikin: A Review ⋆

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Abstract

Thermoregulatory manikin can simulate complex physiological human behaviors such as sweating, shivering and vasomotion which the human body uses in order to adapt to temperature changes in the environment. Thus, it serves as a better simulation for human responses in the thermal environment than traditional ones. This paper first discusses the limitations of traditional manikins then followed by a summary of suitable thermal physiological models which have been implemented on manikins. A review of the development and application of thermoregulatory manikin is made by comparing research achievements of different research institutes. Currently, the thermal manikin system controlled by thermal physiological model has yet to be matured, which needs further validation before laboratory applications.

Keywords: Physiological Model; Thermal Manikin; Controlling System; Shivering; Vasomotion

1 Introduction

Thermal manikin can simulate both heat and moisture transferring processes in human body-clothing-environment system. For the advantage of giving more stable test results than human tests, thermal manikin is widely used in fields like clothing, traffic safety, aerospace and so on. Nowadays, there are more than 100 thermal manikins in the world [1]. Some of them have a multi-zone heating structure, which could simulate human body postures and movements like sitting and walking; some of them have a sweating and even breathing system, allowing precise simulation of heat and moisture transfer process.

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With the development of environmental and biological science, some scholars [2, 3] have reported limitations in the lack of simulation for human thermal physiological regulation mechanisms. Due to behaviors such as shivering, vasomotion which the human body uses to adapt to temperature changes in the environment, there is a deviation in skin temperature between the results of human tests and manikin tests. In addition, uneven skin temperature distribution, body core temperature, etc. cannot be simulated and predicted instantaneously by most traditional manikins.

New development of the thermal physiological model solved this problem to some extent. Researchers tried to apply the model to the manikin system to make a real simulation of human body. The thermal manikin controlled by a thermal physiological model is called as thermoregulatory manikin. The main difference between a traditional manikin and a thermoregulatory manikin is that the thermoregulatory one is controlled by interacting systems of thermoregulation model, whereas the traditional one is commonly controlled by given temperature or a linear comfort mode. However, as the thermoregulatory manikin is used in various fields, the achievements made by different institutes vary greatly. Some leading institutes are already on the way to validate thermoregulatory manikin by clothing test [4]. Few researches have been published on this subject and even fewer have reported significant findings. Therefore, this paper reviews the development of thermoregulatory manikin by discussing the limitations of traditional thermal manikin while enlisting the development of different thermal physiological models and summarizing thermoregulatory manikins. Conclusion is drawn based on current research reviews and future trends are predicted. The thermal physiological models and the thermoregulatory manikins discussed below are selected as they are relatively advanced or typical in this field.

In the past, thermal physiological indexes are mainly derived from human tests. However, extreme testing conditions may be harmful to human subjects. Using the thermoregulatory manikin to replicate human test will yield higher stability with practicability in extreme conditions. Thus, we hope this report will attract researchers' attention in this new area and help researchers to better understand the necessity to use thermoregulatory manikin for evaluating clothing performance.

2 The Limits of the Traditional Manikin System

Previous researchers used physical methods to improve manikin performance such as making the body parts movable [5] and creating sweating [6] or breathing systems [7]. However, the human body is a much more complex organism. In addition to the physical structure, it also has an intelligent physiological adjusting mechanism such as the nervous regulation and the hormonal regulation. In previous studies, researchers seemed to focus only on physical improvement of manikin, while attention paid to physiological effects are comparatively less.

The ISO15831: 2004 Standard states that: during the manikin test of clothing insulation, the manikin surface temperature should be constant and equivalent to 34 °C [8]. However, this is not consistent with the reality. First, human skin temperature values varies in different body parts. Secondly, influenced by human thermoregulation effect, skin temperature is constantly changing over time as the environment changes.

In order to simulate thermoregulation mechanism, the Comfort Equation (CE) mode is applied to the manikin system. However, the comfort equation mode is derived from Fanger model [9],