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Numerical Investigation on Convective Heat Transfer of Infants and Adults under Ventilation ⋆

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Abstract

There is a severe lack of research on the heat transfer mechanisms for various populations, with most studies primarily concentrating on adults. This study aimed to investigate the difference in the convective heat transfer coefficient (h_c) of the whole and individual body parts between infant and adult under ventilation. A numerical model for heat transfer between the human body and the environment was developed and validated against experiments involving a baby thermal manikin. The temperature and airflow fields surrounding the human body and the value of h_c were simulated under seven air velocities ranging from 0.1 m/s to 2.5 m/s. The results indicated that, under natural ventilation, the overall h_c for infants and adults was 4.82 W/m^2·K and 4.29 W/m^2·K, respectively. Infants exhibited higher regional h_c values at their surface than adults, especially on their hands and feet. This discrepancy was more pronounced as the air velocity increased. Furthermore, regression equations were developed for the two body sizes to establish the connection between h_c and air velocity. These findings contribute to a better understanding of the complex interplay between body size and convective heat transfer, providing fundamental data for enhancing the accuracy of infant thermal response predictions by incorporating more precise boundary conditions.

Keywords: Convective Heat Transfer Coefficient; Numerical Simulation; Body Size; Infant; Air Velocity

1 Introduction

The convective heat transfer coefficient (h_c) at the surface of the human body plays a critical role in determining the heat transfer between the human body and the environment. It is also an essential input parameter in human thermal regulation models to predict thermal responses

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or comfort [1]. To date, many manikin tests and numerical studies have been performed to measure the value of this coefficient under diverse conditions. However, most research in this area has focused on male or female adult body shapes, while populations with other body sizes have received little research attention.

Infants, characterised by their distinctively smaller body size and shorter length than adults, exhibit unique thermal characteristics. The smaller characteristic length theoretically leads to a lower Rayleigh number (Ra) and a higher h_c under natural convection. As a result, infants are more susceptible to thermal environments and experience faster heat loss at low temperatures than adults. To accurately measure the value of h_c for infants, researchers have developed manikins that mimic the body size of infants, enabling the measurement of h_c under natural convection [2, 3]. Recently, numerical models have been constructed to visualise airflow patterns and temperature distributions inside neonate incubators and simulate convective heat transfer [4-6]. Nevertheless, the coefficients from this research are difficult to compare with the results from adult research due to inconsistent body postures or varied testing conditions.

Fukazawa et al. [7] employed two types of thermal manikins (a female adult shape with a height of about 168 cm and an infant shape aged six months with a height of 65 cm) in an artificial chamber with a uniform environmental condition to compare the difference in the h_c between adult and infant. The results indicated that the overall h_c for the adult manikin was 3.9 $W/m^2 \cdot K$, while that for the infant manikin revealed 6.2 $W/m^2 \cdot K$. For regional body parts, significantly larger h_c values at the head, back trunk and upper limbs were observed for infants. It is important to note that this research was only conducted under natural convection. However, higher air velocity may occur, especially on outdoor occasions, which differs from that commonly encountered indoors. Infants under one-year-old are often exposed to forced convective flow generated by indoor ventilation systems or outdoor air. This presents a potential risk of rapid heat loss for infants in windy conditions. Since infants have poor abilities to regulate body temperature [8], it is necessary to evaluate the convective heat transfer of infants and discern the differences from adults under the effects of wind.

The current study aims to examine and compare the convective heat transfer between infants and adults under natural and forced ventilation, utilising validated Computational Fluid Dynamics (CFD) models. To achieve this, simulations were performed at seven levels of air velocity ranging from 0.1 m/s to 2.5 m/s, covering the typical range of air speed in indoor and outdoor environments. This study provides specific information on the airflow near individual body parts of infants and adults, and the formulas were developed for predicting regional h_c for both populations. These findings contribute to a better understanding of the complicated interplay between body size and convective heat transfer under varied air velocities and provide basic data for predicting human thermal response with more accurate boundary conditions. From a practical standpoint, the specific guidance on thermal protection for infants will be made referring to adult caregivers, especially addressing the vulnerability of certain body parts.

2 Methodology

To investigate and visualise the heat transfer around the human body, the first step of this study was to determine the method of CFD simulation. Infant manikin experiments were conducted in an artificial climate chamber. The airflow and temperature distributions inside the chamber, as well as the heat loss of baby manikin, were predicted using COMSOL Multiphysics 5.6 (COMSOL,