

論文の内容の要旨

論文題目 Evaluation of the clothing heat transfer coefficients based on
experiment and CFD analysis
(実験と数値解析による着衣熱伝達率に関する研究)

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This thesis focuses on evaluating convective and radiative heat transfer coefficients and clothing insulation for a clothed human body. Moreover, it provides a database of heat transfer coefficients and clothing insulation for various types of clothing.

To study human thermal comfort, it is crucial to understand the heat exchange between the human body and the surrounding environment. The heat exchange characteristics of each segment of the human body can be evaluated using convective and radiative heat transfer coefficients. In recent years, experimental and numerical methods for calculating the convective and radiative heat transfer coefficients using thermal manikin or computational thermal manikin have been proposed. However, although there are numerous studies on heat transfer coefficients for naked manikins, only a few have focused on heat transfer coefficients for clothed manikins. In previous studies, clothing heat transfer coefficients have been approximated by multiplying the heat transfer coefficients of a naked human body by the clothing area factor. Thus, to accurately assess human thermal comfort, it is necessary to determine the heat transfer coefficients for a clothed human body. Furthermore, although substantial literature provides information on convective and radiative heat transfer coefficients for a naked human body, a considerable amount of uncertainty still exists regarding naked convective heat transfer coefficients caused by vertical airflow (Figure 1) and naked radiative heat transfer coefficients.

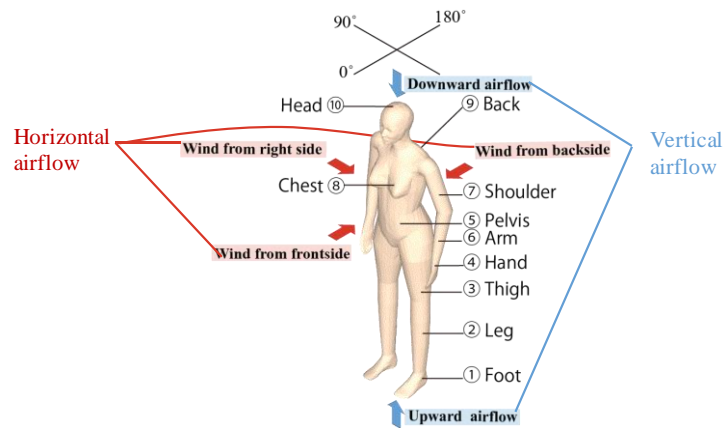


Figure 1. Thermal manikin and wind directions.

Moreover, clothing insulation is also an important parameter for evaluating human thermal comfort. Prior to the year 2000, research on clothing insulation was widely performed; however, recently, only a few studies on this subject have been carried out. In addition, owing to the advances in material engineering, clothing materials have become very diversified. For example, windbreakers and fleece coats are now made of breathable-waterproof material and raised fabric, respectively. Therefore, it is important to elucidate the thermal resistance characteristics of clothes made of such new materials. In addition, with the development of multi-segment thermoregulation models, there is a great demand for information on clothing insulation of different body segments.

Considering the above-mentioned context, the four themes (Chapter 4–7) shown in Figure 2 are addressed in this thesis.

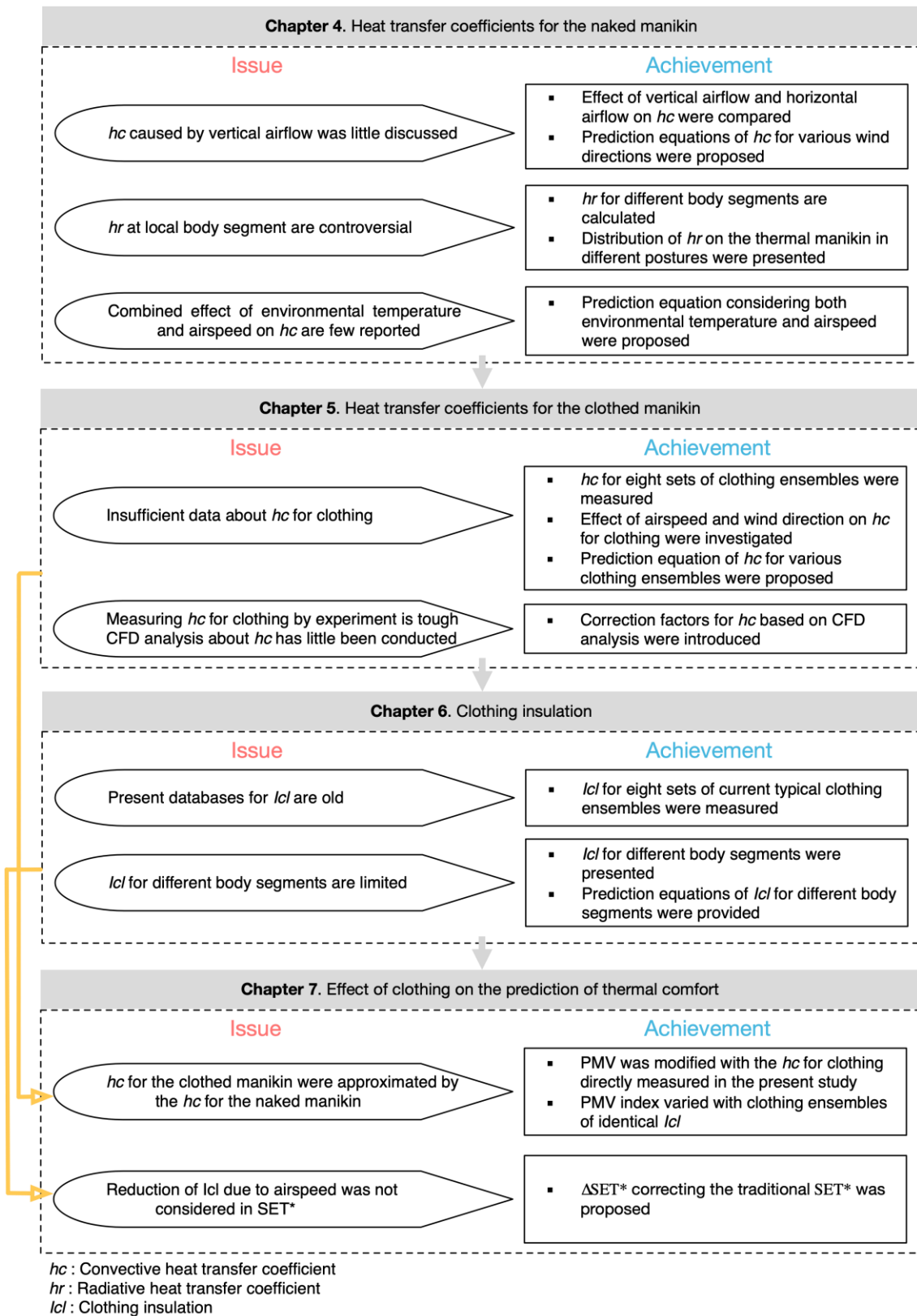


Figure 2. Main topics and results of the present thesis.

For the heat transfer coefficients for the naked manikin, the effects of vertical and horizontal airflows on convective heat transfer coefficient were compared. As there were insufficient data on radiative heat transfer coefficients for the different body segments, a numerical calculation was conducted to present detailed distribution of radiative heat transfer coefficients on the surface of the thermal manikin under various postures. Furthermore, prediction models for convective heat transfer coefficients based on both environmental temperature and airspeed were proposed, thus making it possible to evaluate convective heat transfer coefficients under various environmental conditions.

Concerning the heat transfer coefficients for the clothed manikin, the convective and radiative heat transfer coefficients for eight sets of clothing ensembles were measured using a thermal manikin. Experimental results indicated that convective heat transfer coefficients varied with clothing ensembles. However, the difference between the radiative heat transfer coefficients for the various clothing ensembles was negligible. Additionally, the effects of wind direction and airspeed on clothing convective heat transfer coefficients were confirmed. However, measurement of convective heat transfer coefficient is an arduous task and thermal manikin is not easily available. Thus, correction factors for clothing convective heat transfer coefficient based on (computational fluid dynamics) CFD analysis were presented.

For the clothing insulation, whole-body clothing insulation and local clothing insulation for eight sets of current typical clothing ensembles were reported. In addition, calculation for clothing insulation based on posture, wind direction, and airspeed was suggested.

Furthermore, it was necessary to examine how the different calculated clothing heat transfer coefficients and clothing insulation affect the prediction of thermal comfort. Hence, the convective heat transfer coefficient and clothing insulation directly measured in the present study were introduced to the PMV, SET*, and PET calculation program. The results indicated that the PMV and PET indices varied with clothing ensembles when clothing insulations were almost identical. Moreover, a correction factor ΔSET^* was proposed to consider the reduction of clothing insulation due to airspeed.

Clothing significantly affects human thermal comfort as it determines the heat loss from the human body to the environment. Detailed investigation on clothing convective and radiative heat transfer coefficients will lead to a better understanding of the heat transfer through clothing.

The comprehensive database for convective and radiative heat transfer coefficients and clothing insulation provides a basis for research on thermal comfort, such as personal air conditioning system, low-energy personal wearable device, and energy optimization associated with thermal comfort.

Moreover, the parameters obtained in the study can be used as input data for several thermal comfort evaluation models and indices such as the PMV index, standard effective temperature, and two-node model. These parameters will play an important role in accurately simulating the human thermal comfort.