博士論文(要約)

The Impact of Urban and Individual Characteristics on the Thermal Physiology of Pedestrians

（都市と個人の特性が歩行者の人体温熱生理応答に及ぼす影響）

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Thermal physiology plays an important part in the health and quality of life of urban dwellers. Single meteorological parameters such as air temperature have been shown to be insufficient for describing outdoor human thermal environments. This study explores the urban and individual characteristics influencing the thermal physiology of pedestrians in urban areas. A total of six outdoor traverse field experiments were conducted in three sites in central Tokyo during summer to study urban influences, with Japanese males in their 20s as subjects. Controlled indoor experiments were also conducted in a climate chamber to explore variations in thermal physiological response between demographic groups and anthropometry. Four demographic groups were chosen for the indoor experiments, namely males in the 20s (young males), males in their 60s (elderly males), females in their 20s (young females) and females in their 60s (elderly females).

During indoor experiments, it was observed that the Body Mass Index (BMI) of subjects was positively correlated with steady-state core temperatures (T_c). Subjects with lower BMI had generally lower skin temperature at the extremities (arms and legs). Subjects with higher BMI had slightly lower trunk (chest and shoulder) T_{sk} but higher T_{sk} at extremities. While walking, core heat gain (ΔT_c) of subjects were not well correlated with their anthropometric parameters. Skin heat gain (ΔT_{sk}) had a tendency to decrease with increasing BMI. Subjects with higher BMI were found to have differing heat gain patterns at their arms from subjects with lower BMI, who underwent more cooling. Overall sweat rates were found to be positively correlated to BMI. Controlling for BMI and body surface area (BSA) differences, males were found to sweat more than females, which is in agreement with previous research, but not always accounted for in human thermal models.

While stationary ground and rooftop measurements have been used in many outdoor thermal comfort studies, the findings from the outdoor experiments in the present study showed that stationary ground sensors and stationary rooftop sensors did not agree well with continuous mobile measurements of micrometeorology. This suggests that experiments involving transient outdoor thermal comfort should be accompanied by mobile sensors for representative meteorological observations at the street level. Higher correlation was found between skin temperature (T_{sk}) of subjects and meteorological variables while subjects were walking in the street canyon, particularly when mean radiant temperature (T_{mrt}) was high as subjects were in the open and during the early afternoon. During mild radiant conditions, wind speed becomes influential in terms of effect on the skin temperature of subjects. Conversely, while subjects were seated and recovering from exercise in the shade, the above relationships became weaker, suggesting that individual physiological differences were more influential than urban effect during recovery. Street orientation and height-width ratio (H/W) were also found to affect the thermal physiology of pedestrians through their influence on experiential radiant and wind conditions.

The empirical findings from the experiments have implications for modelling and future experiments. Set-point body (core and skin) temperatures are closely related to steady-state body temperatures, which were in turn shown to differ based on anthropometry and demography. This being the case, constant set-point temperatures (used in models such as the Gagge two-node model) will not be able to account for differences due to anthropometry (especially body fat percentage or BMI) and demography. The above is important because set-point temperatures account for thermoregulation (sweating and heat transfer by blood flow) in the models. The wide variation in mean skin temperature of body parts among demographic groups found in the present study means that having larger number of sensors on different body parts is crucial to obtaining accurate mean T_{sk}. Localised comfort may also be important when considering thermal comfort across different demographic groups.

A modified version of the Gagge two-node model was used to simulate the thermophysiology of pedestrians. Modifications were made iteratively using findings from the empirical analysis and literature review. For example, parameterization of sweat rate with BMI taken into consideration was important and included in the modification. The model was tested against published research data as well as observation data from the outdoor experiments, and performed well, particularly against the original two-node model. Microclimate simulations were also conducted using the ENVI-met CFD model. Initial meteorological conditions were input in accordance with actual experiment conditions. A comparison of model output and observation data showed generally agreeable trending and magnitude of values. Some inaccuracies were attributed to the parameterization of soil and vegetation and surface materials.

Scenario simulations were also conducted using both models above to simulate the transient body energy balance of pedestrians traversing an urban area, while assessing the effects of changes to urban characteristics, micrometeorology and individual differences. Some findings include the effect of reflective wall surfaces increasing T_{mrt}

in narrow streets and the importance of cloud cover, vegetation cover and pavement reflectance on experiential thermal conditions that pedestrians face. Scenario analysis suggests that individual and environmental variations in thermal physiology are present when considering different environmental changes. The type of people using an urban area of a specific design is hence important when considering bioclimatic urban design. Some common suggestions on bioclimatic design to cool buildings, such as reflective pavements, were found to have negative outcomes for pedestrians on the street through the simulations.

Overall, the present research also managed to move away from just looking at an "average person" and homogenous groups, towards accounting for differences between individuals not previously covered in literature. The use of a transient approach to pedestrian thermal physiology and methodologies also shed light on new findings. Last but not least, the consideration of urban and individual simultaneously through microclimate and body energy balance simulations allowed for analysis on how different subjects of different demographic groups and anthropometry are affected by urban changes.