

## 論文の内容の要旨

論文題目 Evaluation of thermal sensation in outdoor environment under mist spraying condition  
(ミスト噴霧を有する屋外環境における温熱感覚評価に関する研究)

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This thesis focuses on how to evaluate human's thermal sensation in mist spraying outdoor environments. The aim of this thesis is to clarify the thermal effects of the mist spraying outdoor environment on a human body and evaluate thermal sensation by proposing a method to predict the thermal state of the human body in these environments.

In recent years, a mist spraying system has been widely used to mitigate the fatal heat disorder of an outdoor environment during the summer season. Many studies reported that cooling effects by mist spraying are effective to improve the human's thermal sensation and thermal comfort. However, these results were mainly obtained through a survey research method, and there is a lack of quantitative understanding of the thermal effects of sprayed mist. Moreover, experimental studies in this field are limited since most of them are focusing on the measurement of two basic environmental factors such as temperature and humidity. A comprehensive investigation into mist spraying environments by measuring overall environmental factors is insufficient.

A field experiment of the mist spraying system has difficulty since it must be proceeded in outdoors in sunny days during the summer season, and the influence of the outdoor environmental factors on the human body is non-uniform and complex. For these reasons, it is difficult to clearly identify how the sprayed mist particles affect the human's thermal sensation and thermal comfort. Therefore, in the present study, experiments were conducted gradually for every summer for three

years to measure the variations of overall environmental factors (temperature, radiation, humidity, and airspeed) due to mist particles in an outdoor environment, and the impact of these variations of environmental factors on improving thermal sensation and thermal comfort was evaluated. Moreover, the thermal state of the human body was investigated by measuring skin temperatures. Based on the experimental results, the physiological human model was developed which could predict the thermal state of the human body in outdoor and mist spraying environments well, and the environmental index was proposed to evaluate the thermal sensation using the prediction model.

The first experiment was conducted as a preliminary study. The effects of the mist spraying system on the human's thermal sensation and thermal comfort and the suitability of the existing environmental indices were examined. Specifications including outline, results, and analysis of the preliminary experiment are described in Chapter 3, and the details are as follows.

Evaluation of thermal sensation based on survey results and suitability existing environmental indices (Chapter 3)

- 1) Survey on variations in thermal sensation and thermal comfort between outdoor and mist spraying environment (n = 1,110)
- 2) Examine the feasibility of conventional environmental indices (SET\*, PET, WBGT, and UTCI) by measuring four environmental factors (temperature, radiation, humidity, and airspeed) in mist spraying environment

In the preliminary experiment, survey results showed that the subject's thermal sensation and thermal comfort were improved after they experienced the mist spraying environment. However, based on these survey results, the improvement level of the human's thermal sensation under certain environmental conditions cannot be grasped, and conventional environmental indices cannot be utilized to reflect the human's thermal sensation in the mist spraying environment appropriately. In order to solve this problem, not only the environmental factors of the mist spraying environment but also the skin temperatures of the subjects were measured through the second experiment. Based on the results from the second experiment, the validity of the prediction model to predict the physiological response of the human body was investigated. In addition, a correlation between the reported thermal sensation in the survey and the predicted results from the physiological model was analyzed to propose an evaluation method of human's thermal sensation which can be appropriately utilized in the outdoor and mist spraying environment. Further details are described in Chapter 4 including the following details:

Evaluation of mist spraying environment considering human's physiological responses (Chapter 4)

- 1) Survey of human's thermal sensation and thermal comfort in outdoor mist spraying

environment (n = 12)

- 2) Measurement of environmental factors (temperature, radiant temperature, humidity, wind speed) in outdoor and mist spray environments and verification of the evaporative cooling effect of mist spraying system
- 3) Investigation of the thermal state of human body in outdoor and mist spraying environment by measuring the skin temperature
- 4) Prediction of skin temperature using measured environmental factors and two-node model, and verification of its feasibility by comparing with experimental results (Chapter 4)
- 5) Proposal of the new index (outdoor predicted mean vote (O-PMV)) to estimate human's thermal sensation in outdoor and mist spraying environment based on the correlation analysis between the reported thermal sensation in the survey and the predicted results from the physiological model (Chapter 7)

As a result of the second experiment, it was found that the skin temperature of the human body in the outdoor and mist spraying environment can be predicted with high accuracy by using the conventional two-node model. However, because of the deficient number of subjects participated in the experiment, it was difficult to generalize this given fact.

As in Experiment 2, the skin temperature was well predicted under the shaded mist spraying environment condition, but there is a difficulty in predicting the skin temperature under non-shaded mist spraying environments. Moreover, the subjects reported that the mist spraying environment felt cooler than the outdoor environment under the same condition of heat load. Therefore, it was necessary to examine the influence of another environmental factor other than the basic four environmental factors (temperature, radiant temperature, humidity, airspeed). Since it is not known how much the evaporative heat loss at the human body surface caused by mist particles (mist wettedness) contributes to the cooling effect of the mist spraying system, an additional experiment was conducted to clarify this. In Chapter 5, the detailed overview, methodology, results, and analysis from the additional field experiment to consider the mist wettedness are described as follows.

Evaluation of mist spraying environment considering mist wettedness (Chapter 5)

- 1) Survey of human's thermal sensation and thermal comfort in outdoor and mist spraying environments according to the different operating conditions of mist spraying system (n = 65)
- 2) Examination of subjects' skin temperature variations according to the different operating conditions of the mist spraying system (n = 65)
- 3) Verification of the cooling effect of the mist spraying system by measuring the environmental factors in outdoor and mist spraying environments.

- 4) Proposal for the mist wettedness measurement method and its measurement.
- 5) Development of prediction model to predict a human's physiological response considering mist wettedness and its prediction accuracy by comparing with experimental results.

By suggesting an appropriate measuring method, the prediction model to predict human's physiological response was possible to be improved considering a mist wettedness. As a result of the developed prediction model considering the factor of mist wettedness, the skin temperature of the human body surface in outdoor and mist spraying environment could be estimated more accurately compared to the conventional prediction model, with a small temperature error of 0.5 °C between the experimental data. In conclusion, in outdoor environments, heat loss due to sweating was shown as 90% of total heat loss and it was the largest contributor. In mist spraying environments, convective heat loss due to the temperature drop was the largest, and the heat loss due to the mist wettedness was the second contributor which was shown to be 30%. Given this fact, it was found that the mist wettedness was the major environmental factor in the mist spraying environment.

In conclusion, based on the results of the three-step field experiment and its analysis, this thesis proposes the following three methods to clearly evaluate the human's thermal sensation in outdoor and mist spraying environments (Chapter 7).

- 1) Evaluation method using the correlation analysis between the heat load of the human body and the thermal sensation reported by the subject (O-PMV)
- 2) Evaluation method using prediction of human physiological response considering mist wettedness (SET\*\*)
- 3) Evaluation method using correlation analysis between heat load using PMV calculation and thermal sensation reported by the subject (modified predicted mean vote (mPMV))