An evaluation of the thermal environment based on skin temperature of occupants controlling composite heating

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ABSTRACT
In Korean residential buildings, most occupants frequently use the floor heating systems together with diverse types of auxiliary heating devices such as heating mat. The skin temperature and TSV at each body parts of occupants were obtained from the field survey for the comparison of two values to evaluate the thermal environment. The distribution of skin temperature was examined through field measurement, and it was revealed the skin temperature on backside of the thigh of occupants 5.7℃ higher than the average skin temperature of 31.33℃. The thermal sensation determined by the skin temperature of occupants was plotted on the scatter diagram and the occupants were found commonly sensitive to the drop of feet temperature and rise of thigh temperature.

KEYWORDS
Non-uniform conditions, Thermal Sensation, Skin Temperature, Heating mat

INTRODUCTION
According to the results obtained from the questionnaire collected from approx. 200 domestic households (Yoon and Kang, 2015), most of domestic households appeared using the floor heating systems of residential buildings together with auxiliary heaters. The representative type of auxiliary heater was the heating mat (Yoon and Kang, 2015) showing the dominant lifestyle of most Koreans relying on the direct thermal contact with heated floor surface. The occupants thereby exposed to non-uniform thermal conditions in wintertime and this will determine the behavior of occupants using heaters or operating heating systems in residence. This study was designed to examine the thermal responses of occupants exposed to non-uniform thermal conditions in respect of the field measurement of local skin temperature to identify the relationship between thermal sensation and skin temperature of occupants.

METHOD

Outline of Experiment
The experiment was carried out in the single space of room (of approx. 18m^2). The radiant floor heating system and a heating mat were used to construct the non-uniform

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thermal condition. Figure 1 represents the floor plan showing the positions of measurement points and subjects. The indoor temperature, relative humidity, air velocity, MRT, and skin temperature were measured. There were 12 subjects in their 20s and 30s participated in the experiment. The T_{indoor} was determined by referring to results of the study that examined the heating behavior of Koreans (Yoon and Kang, 2015). The entire experiment continued for 50 minutes and it was divided into the initial stage lasted for 20 minutes for the sole application of the radiant floor heating and the next stage lasted for the remaining 30 minutes for the simultaneous application of floor heating and the use of heating mat. The subjects went through the 20 minutes of waiting time intended to attain the thermal neutrality before entering into the actual experiment.

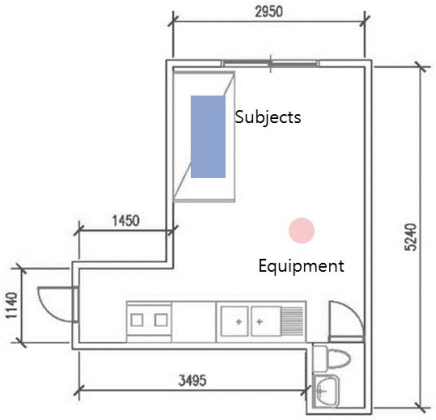

Figure 1. *Plans of the room and measurement points*

The ALMEMO was employed for the measurement of thermal environment whereas the skin temperature of subjects was measured from the T-type thermocouples put on 7 body parts (head, abdomen, arm, hands, front of thigh, backside of thigh, calves, and feet) of subjects. The thermocouples were put on the front and backside of the thigh because the T_{skin} was dependent on the contact with the heating mat.

RESULTS

Environmental parameters

The average values of the T_{indoor} of 22.5℃, air velocity of 0.07m/s, MRT of 22.3℃, and RH of 47.2% were kept for the experiment.

The mean skin temperature was calculated from measured T_{skin} of 7 body parts that included the average thigh temperature calculated from the temperatures on the front and backside of the thigh of subjects. The following equation (1) (Hardy and DuBois, 1938) was referred to for the calculation of MST.

$$MST_{skin} = 0.07 \times T_{skin,forehead} + 0.35 \times T_{skin,abdomen} + 0.14 \times T_{skin,lowerarm} + 0.05 \times T_{skin,hand} + 0.19 \times T_{skin,upperleg} + 0.13 \times T_{skin,lowerleg} + 0.07 \times T_{skin,foot} \quad (1)$$

The T_{skin} revealed significant difference between each body parts as represented in Figure 2. The MST calculated from equation (1) was 31.33℃ (S.D. 0.3273), and the value appeared stable over time.

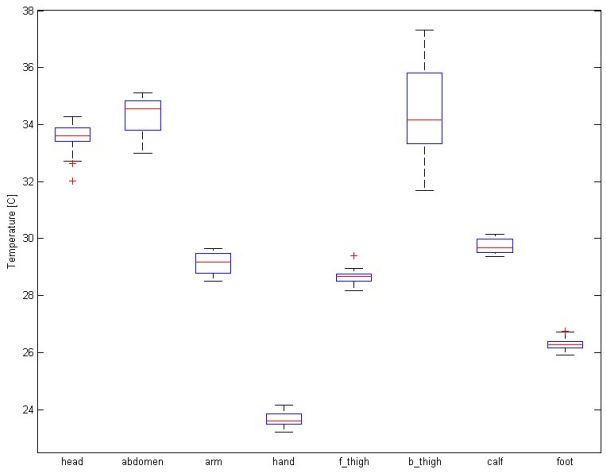

Fig 2. *Local Skin Temperature Distribution*

The backside of thigh T_{skin} marked the maximum 37.33℃ among relatively higher level of others. This was due to the direct contact of the backside of the thigh with the heating mat. Besides, it showed the biggest variance of S.D. 2.52. This was estimated that it would be attributable to the rapid increase of T_{skin} by the heating mat turned on 20 minutes after the initiation of the experiment. Thereafter, the backside of thigh T_{skin} tended to increase over time. Contrastingly, the average T_{skin} of calves was 29.73℃ similar to that of the front thigh (28.65℃). However, the average T_{skin} of the hands and feet were 23.63℃ and 26.29℃ respectively and marked the lowest level comparing to those of the head (33.6℃) and abdomen (34.32℃). This analogize with the results of the study reported the lowest skin temperature of hand and ankle (Wang, 2015).

Thermal responses and skin temperature

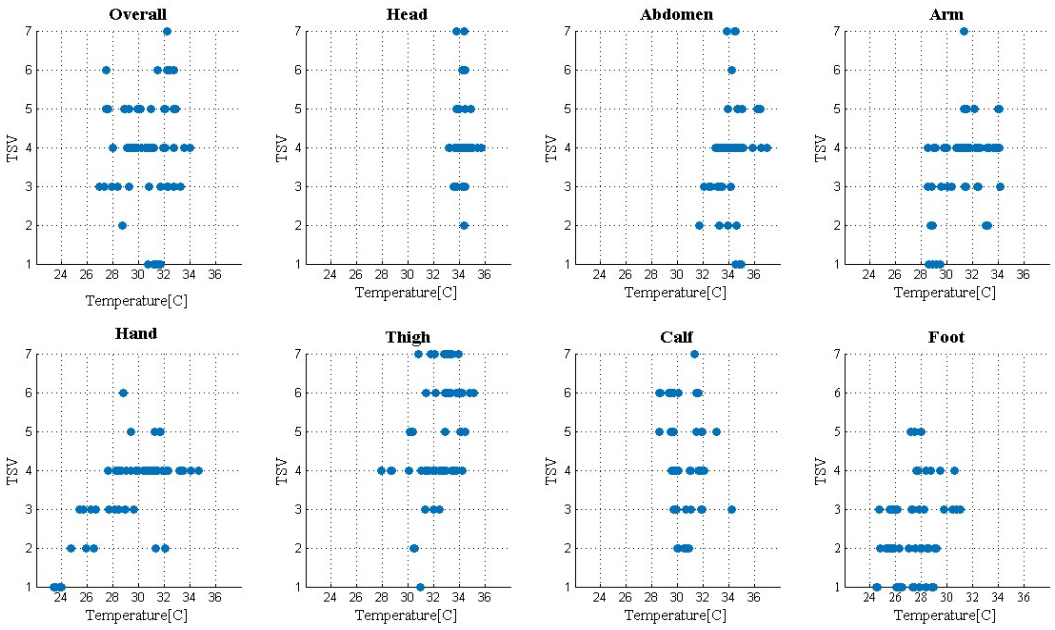

Figure 3. *Distribution of thermal responses by local skin temperatures*

The TSV results and local T_{skin} scatter plotted in the following Figure 3. As illustrated in Figure 2 of the distribution of T_{skin}, the replied level of TSV of hands and feet was low. What was interesting in the votes was the thermal sensation of the feet appeared lower than that of the hands despite the higher level of T_{skin}. In cases of the sensation of the head and abdomen showing less variation in the T_{skin}, each of 68% and 58% of the subjects voted for the 'neutrality'. By comparing with that shown in Figure 2, the distribution of TSV of the thigh (S.D. 1.42) was relatively smaller than that of the T_{skin} (S.D. 2.51). On the contrary, the TSV of calf (S.D. 1.38) varied broadly than that of the T_{skin} (S.D. 1.16).

CONCLUSION AND IMPLICATIONS

The results from the experiment showed significant difference in local skin temperature despite the indoor temperature set to the neutral level of 22℃. This implies the sensitivity on each body parts that affects the thermal sensation of subjects varies. Besides, the change in local skin temperature could be the source of local discomfort. This will then lead to the changes in behaviors (clo, posture) or physical factors (set point temperature). For the analysis thereof, an examination on thermal comfort under non-uniform thermal environment should be preceded.

ACKNOWLEDGEMENTS

This research was supported by a grant (No. 2014R1A2A2A01006494) of Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning, Republic of Korea.

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