Wind Engineering Joint Usage/Research Center
FY2018 Research Result Report

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Research Field: Indoor Environment
Research Year: FY2018
Research Number: No. 182006
Research Theme:
Research on Local Cooling Ways to Human Thermal Comfort in Hot Environment

Representative Researcher: Zhiwei Lian

Budget [FY2018]: 260,000 Yen

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*There is no limitation of the number of pages of this report.
*Figures can be included to the report and they can also be colored.
*Submitted reports will be uploaded to the JURC Homepage.

1.　Research Aim

Nowadays, local heating or cooling of body has become the research hotspot in the field of thermal comfort. According to the existing research, in overheated environment, many products such as cold jet, task-ambient air-conditioning and medical cooling clothes have already developed which use local stimulation to adjust thermal comfort. Most of these researches chose to study on body parts of human to explore the relationship between local thermal stimulation and overall thermal comfort. However, due to the different ambient temperature, local stimulation parts and stimulation methods, the influence of the local thermal stimulation on the overall thermal comfort may be different. Also, the regulation of the local thermal stimulation has a certain limit and it may be affected by the ambient temperature or local stimulation parts to a large extent. Generally speaking, the correlation between the overall thermal comfort and the related factors of local stimulation has not been well studied and solved.

In this case, the research selects the 20-Zone Newton Thermal Manikin as the experimental object. The local body parts of forehead, back, foot and wrist which are easy to wear cooling products are selected to explore the relationship between the local thermal comfort and the overall thermal comfort. For the optimization and supplement of local cooling method, it is hoped that the most suitable body part for local cooling can be found under the specific environment.

2.　Research Method

1）Subject
The Newton 20-Zone Sweating Thermal Manikin used in this experiment was produced by MEASUREMENT TECHNOLOGY NORTHWEST. In this experiment, the thermal resistance of clothes is about 0.5 clo (the manikin is dressed with T-shirt and shorts to simulate summer conditions), and the given heating power is 69.78W/m. The skin temperature of the thermal manikin is controlled by the built-in sensor, and when a working condition is completed, the skin temperature of each point is directly derived.

2）Experiment design
The experiment controlled the temperature and humidity of each working condition. The fluctuation of indoor temperature was basically controlled in the range of 0.5 C, and the humidity was maintained at 55% RH. Meanwhile, the indoor air speed was measured by hot-ball anemometer, and the background air speed was kept 0.1m/s during the test period.

Based on the orthogonal experimental design, the parameters in the research were set as three factors and three levels shown as Table1. And the experimental conditions and supplementary conditions are shown as Table 2 and Table 3.

Table 1. Experimental Factors and Levels

Factor / Level	Ambient temperature	Local temperature	Body part
1	28℃	22℃	Back
2	31℃	24℃	Forehead
3	34℃	26℃	Foot (wrist)

Table 2. Experimental Conditions

	Ambient temperature	Local temperature	Body part
1	1(28℃)	1(22℃)	1(Back)
2	1(28℃)	2(24℃)	2(Forehead)
3	1(28℃)	3(26℃)	3(Foot)
4	2(31℃)	1(22℃)	2(Forehead)
5	2(31℃)	2(24℃)	3(Foot)
6	2(31℃)	3(26℃)	1(Back)
7	3(34℃)	1(22℃)	3(Foot)
8	3(34℃)	2(24℃)	1(Back)
9	3(34℃)	3(26℃)	2(Forehead)

Table 3. Supplementary Conditions

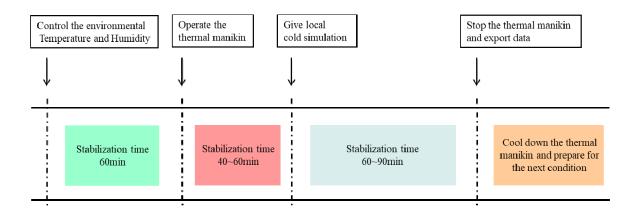|	Ambient temperature	Local temperature	Body part
1	1(28℃)	3(26℃)	3(wrist)
2	2(31℃)	2(24℃)	3(wrist)
3	3(34℃)	1(22℃)	3(wrist)

3）Measurements
A large number of literatures have indicated that it is feasible to use mean skin temperature (MST) as an objective index to evaluate human thermal comfort. The ten-point method is reliable and the formula is as follows.

$$MST = 0.06T_{Forehead} + 0.08T_{R\,Upper\,Arm} + 0.06T_{L\,Forearm} + 0.05T_{R\,Hand} + 0.12T_{Back} + 0.12T_{Chest} + 0.12T_{Stomach} + 0.19T_{R\,Thigh} + 0.13T_{R\,Calf} + 0.07T_{R\,Foot}$$

where MST is mean skin temperature, T is the temperature of each body part.

4）Experiment procedure

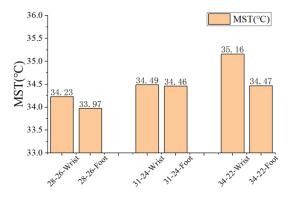| Control the environmental Temperature and Humidity | Operate the thermal manikin | Give local cold simulation | | Stop the thermal manikin and export data |
| Stabilization time 60min | Stabilization time 40~60min | Stabilization time 60~90min | | Cool down the thermal manikin and prepare for the next condition |

5）Statistical analysis

Orthogonal table can sample equally in the range of factors, which makes each experiment more representative. After the orthogonal experiment results are obtained, variance analysis is carried out with SPSS software to distinguish whether the different experimental results are caused by the change of factors or experimental errors. Also, it can test whether the factors have an impact on the experimental results and whether they are significant.

3. Research Results

1）Under the same ambient temperature and local temperature, it can be seen from the figure that foot stimulation is better than wrist stimulation in lowering MST.
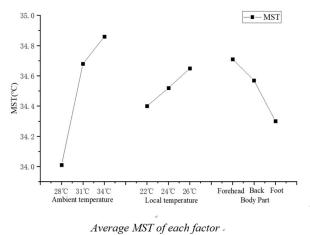

2）From Tab.4 it can be seen that ambient temperature and body part of simulation have significant influence on human thermal comfort ($P < 0.05$), while local temperature of simulation has no significant effect ($P > 0.05$). The influences of these factors on human thermal comfort from large to small are ambient temperature > body part > local temperature.
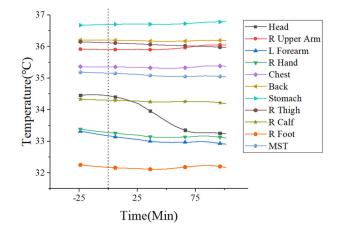
Table 4. Variance Analysis Datasheet of SPSS

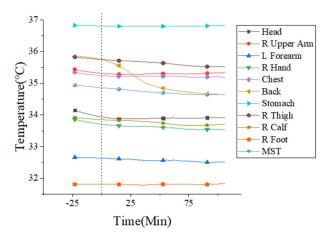|	Square Sum III	d_f	Mean square	F	Sig.
Correction model	1.475a	6	0.246	60.281	0.016
Intercept	10728.126	1	10728.126	2630875.556	0.000
Ambient temperature	1.124	2	0.562	137.839	0.007
Body part	0.257	2	0.128	31.507	0.031
Local temperature	0.094	2	0.047	11.496	0.080
Error	0.008	2	0.004		
Total	10729.609	9			
Total corrections	1.483	8			

3）The most effective body part of stimulation to lower MST can be seen from the figure is foot, back and forehead in turn.
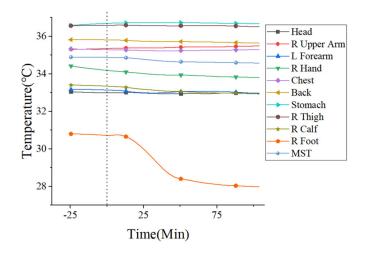

Average MST of each factor

4）Head Stimulation: Head temperature gradually stabilizes after decreasing. MST and other local skin temperatures do not decrease significantly.

5）Back Stimulation: Back temperature gradually stabilizes after decreasing and MST decreases slightly and stably. The local skin temperatures of the proximal limbs decrease slightly. The local skin temperatures of the trunk exclude back and the distal limbs are almost unaffected.

6）Foot Stimulation: The skin temperature of foot decreases steadily while the MST decreases slightly. The local skin temperatures of trunk and the upper limb are completely unaffected. The local skin temperature of thigh and leg decreases with the decrease of foot temperature.

7）The development of local cooling products can be considered from cooling down some body parts such as foot and back to improve human thermal comfort in overheated environment.

4.　Published Paper etc.
[Underline the representative researcher and collaborate researchers]
[Published papers]
1. Yiwen Luo, Zhiwei Lian*, Yingli Xuan, Weirong Zhang.　Research on More Effective Local Cooling Ways to Human Thermal Comfort in Hot Environment. *Environmental Engineering*(EI), 2019

2.

[Presentations at academic societies]
1. The 11th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC 2019), Harbin, China, 2019.

[Published books]
None.

[Other]
　Intellectual property rights, Homepage etc.
None.

5. Research Group
1. Representative Researcher: Zhiwei Lian
2. Collaborate Researchers
　　1)　Yingli Xuan
　　2)　Weirong Zhang
　　3)　Kunio Mizutani
　　4)　Yiwen Luo

6. Abstract (half page)

Research Theme:
Research on Local Cooling Ways to Human Thermal Comfort in Hot Environment

Representative Researcher (Affiliation):
Zhiwei Lian

Summary・Figures:
Local heating or cooling of body has been the research hotspot in the field of thermal comfort. This paper analyses the impact of local cooling of forehead, back and foot on overall thermal response under specific environmental parameters. The experiment uses thermal manikin as the subject. Based on the orthogonal experimental design, in a climate chamber with different ambient temperature of 28℃, 31℃, 34℃, local cold stimulation of 22℃, 24℃, 26℃ were given to the different three parts of thermal manikin. According to the average skin temperature recorded, thermal comfort could be evaluated. The results indicated that local cooling of each one of the three parts can reduce the average skin temperature to some extent. The key part of local stimulation is foot > back > forehead. The findings have important implications for the further research.

Average MST of each factor