Effect of Local Radiant Heating on Thermal Comfort in Cold Environment

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Abstract: In cold environment, local radiant heating can improve thermal comfort. In this paper, the local radiant heating equipment was used to heat subjects’ ankles and backs separately at an ambient temperature of 12.5°C and 14.5°C, with the radiant power of 200W, 300W and 500W. The number of subjects was 20. The subjects’ thermal comfort changes were collected through a subjective questionnaire. The results show that local radiant heating can improve human thermal comfort. The effect of radiant heat source located on the back of human body is better than that on ankle. Local radiant heating in cold environment has energy saving effect.

1. Introduction

In earlier period research work, it was suggested that air conditioners do not need to be used in large spaces such as some offices and factories, otherwise it will cause a lot of energy waste[1]. Oi[2] et al. found that when the temperature was below 15°C, the heating seats in the car could greatly improve the thermal comfort of the human body and prevent the decrease of skin temperature. Arens[3] et al. found that in colder environment, the thermal sensation in certain parts of the human body (such as the backs, chests) affected the overall thermal sensation more than the hands and feet. Zhang [4] et al. used local heating equipment to keep the thermal comfort of the human body in an acceptable state at 18-30°C, and improve work efficiency. Zhai [5] et al. studied the effect of installing personalized thermal comfort equipment on human thermal sensation. Paust[6] et al. found that when the ambient temperature was set to 16°C and 18°C, the installation of heating chairs could significantly improve the thermal sensation of the human body, and the thermal sensation of the subjects’ back changed from cold to hot. Jin [7] et al. studied the relationship between the head and the overall thermal sensation of the human body at an ambient temperature of 19°C through a local ventilation device. When the head was sent hot air through the local ventilation device, the heating of the head has an impact on the overall thermal sensation. Lv[8] et al. conducted an experimental study on human thermal sensation in a laboratory at the University of Sydney. The research results showed that in a specific thermal environment, local heating or cooling of indoor personnel could make the human body feel thermal pleasure. Al-Ghamdi[9] et al. chose the heating seats, table pads and carpets to combine or use separately in the experiment, and analyzed the influence on the thermal comfort of the human body. The experimental results showed that the heating seat had the greatest influence.

There are many areas without central heating in China, and the indoor thermal environment is very bad in winter. Large-scale adoption of central heating or air conditioning is bound to greatly increase building energy consumption. Therefore, it is very important to find a local heating method which takes into account saving energy and improving human thermal comfort. In this paper, the local
A radiant heating device is used to heat the ankle and back of the human body, and the influence of local radiant heating on thermal comfort is studied when the ambient temperature is 12.5 °C and 14.5 °C.

2. Experimental Methods and Contents

2.1. Experimental Scheme

The experimental room has an area of about 50 m², with 3 seats and a space between seats of 50 cm. The quartz tube electric heaters used in the experiment were placed 50 cm in front of the subjects with a height of 13 cm to heat the ankles; when heating the back, the heater was placed 50 cm behind the subject with a height of 80 cm.

Under the conditions of indoor temperature of 12.5 °C and 14.5 °C, local radiant heating was applied to the subjects’ ankles and backs respectively. During the test, the indoor relative humidity was 35%~37%, and the indoor air velocity was 0.03~0.04 m/s.

The subjects were 20 college students who participated in the experiment. They were 21-24 years old and in good health with a height of (166±8) cm, a weight of (60±10) kg, and a BMI (Body Mass Index) of 19.0-22.3. The average thermal resistance of subjects' clothing was (0.90±0.14) clo. The determination of thermal resistance of subjects' clothing is based on reference [10].

The subjects entered the preparation room to rest and adapt to the environment 20 minutes before the start of the experiment. The subjects basically remained sitting during the experiment. After changing the heater power for 15 minutes, the forehead surface temperature was tested and the questionnaire was filled in. The questionnaire survey evaluation adopts the classification method of thermal feeling and thermal comfort voting grade, as shown in Table 1 [11].

| Thermal sensation | Thermal comfort     | Vote | -3 | -2 | -1 |
|-------------------|---------------------|------|----|----|----|
| Thermal sensation | Cold                |      |    |    |    |
| Thermal comfort   | Cool                |      |    |    |    |
| Thermal sensation | Very uncomfortable  | Uncomfortable | Slightly cool |
| Thermal comfort   |                      | 0    | 1  | 2  |
| Thermal sensation | Neutral             | Slightly warm | Warm |
| Thermal comfort   | Comfortable         | Slightly uncomfortable | Uncomfortable |
| Thermal sensation | Hot                 |      |    |    |    |
| Thermal comfort   | Very uncomfortable  |      |    |    |    |

2.2. Test Instrument

AET-R1A3 infrared thermometer has a measuring range of 32.0°C~42.2°C and an accuracy of ± 0.2°C. Testo405-V1 anemometer has a measuring range of 0~10 m/s and an accuracy of ±5%. Testo174T temperature and humidity meter has a measuring range of 0~100%RH and an accuracy of ±3%RH. TR-72S black bulb thermometer has a measuring range of 0°C~50.0°C and an accuracy of ±0.1°C.

3. Result Analysis

3.1. Indoor Thermal Environment Parameters

Table 2 shows the indoor thermal environment parameters measured in the experiment.
Table 2. Indoor Thermal Environment Parameters

| Temperature/℃ | Relative humidity/% | Airvelocity/(m/s) |
|---------------|---------------------|-------------------|
| Test case 1   | 12.5                | 35                | 0.03              |
| Test case 2   | 14.5                | 37                | 0.04              |

During the experiment, the indoor relative humidity was low under the two test cases, and more than 90% of the subjects thought the room was relatively dry, which was very close to the subject’s feeling.

3.2. Thermal Sensation Vote (TSV) at 12.5℃ Ambient Temperature

The percentage of TSV at 12.5℃ ambient temperature is shown in Figure 1. It can be seen from Figure 1 that 75% of the subjects felt comfortable when the local radiant heating equipment of 300 W heated the back under an ambient temperature of 12.5°C, and 15% of the subjects felt warm. This is the best heating effect.

Figure 2 shows the TSV changed when radiant heating equipment of different power was applied to different parts of the human body under an ambient temperature of 12.5°C. The experimental results show that when heating the ankles and backs, the thermal sensation of the human body had been improved, and as the radiant power increased, the TSV continued to increase. When the subjects were at an ambient temperature of 12.5°C, the radiant heat source located on the backs of the human body had a greater impact on the thermal sensation than the ankles. When the local radiant power was 300 W and it acted on the back of the human body, the TSV was 0.05, which was the closest to thermal neutrality. And as the radiation power increased, the difference in the thermal sensation of different position of the heat source significantly reduced. During the experiment, the temperature of the human cochlea hardly changed, but the temperature of the forehead surface fluctuated slightly (as shown in Figure 3). The temperature of the forehead surface increased with the increase of radiant power, and when the radiant heat source was located at the ankles, the effect on the temperature of the forehead surface was greater than when the radiant heat source was placed on the back. The reason is that the forehead is selected as the measurement site, and when heating the ankle, the radiant heat source is in front of the human body, so it has an effect on the temperature of the forehead. As a result, the temperature of the forehead is slightly higher when heating the ankles than the backs.
3.3. TSV at 14.5℃ Ambient Temperature

The percentage of TSV at 14.5℃ ambient temperature is shown in Figure 4. The experimental results show that when the local radiant heat source of 200W irradiated the backs under the environment temperature of 14.5℃, 65% of the subjects felt comfortable and 30% of the subjects felt warm, and the heating effect was the best.

Figure 4. TSV at 14.5℃ Ambient Temperature

Figure 5 shows the TSV changed of different power radiant heating equipment acting on different parts of the human body at an ambient temperature of 14.5℃. Experimental results show that after heating the ankles and backs, the thermal sensation of the human body was improved, and as the radiant power increased, the TSV continued to increase. When the subjects were at an ambient temperature of 14.5℃, the heat sensation of heating the backs were still better than that of the ankles. When the local radiant power of 200W acted on the back of the human body, the TSV is -0.2. As the radiant power increased, the difference in the thermal sensation of different position of the heat source gradually decreased. During the experiment, the subjects’ average temperature of forehead surface increased as the radiation power increased (as shown in Figure 6). When the radiant heat source was located at the ankles, the temperature on the forehead surface of the human body was a little higher.
than when the radiant heat source was placed on the backs.

3.4. Energy saving Analysis

The reduction of indoor temperature can reduce the energy consumption of central heating or air conditioning, but it will make the indoor personnel feel uncomfortable in the thermal environment. The use of local heating can improve the thermal comfort of indoor personnel. The power of the local radiant heating equipment used in this experiment is 200W, 300W and 500W respectively. When the ambient temperature is 12.5 °C, the radiation power to achieve thermal comfort is 300W, and when the ambient temperature is 14.5 °C, the radiation power to achieve thermal comfort is 200W, and the radiation part is the back. Suppose a simulated room is 4.5m long, 3.5m wide, and 3.5m high. The west outer wall is equipped with external windows of 2.5m long and 1.5m high. The indoor heating temperature is calculated at 18°C. The outdoor meteorological parameters adopt the outdoor calculation parameters of Hangzhou City, China, and the thermal parameters of enclosure are selected according to reference [12]. The room energy consumption is shown in Table 3.

When the radiant power is 300W, the energy saving rate of the room with local radiant heating combined with central heating at ambient temperature 12.5 ° C is 26% compared with the room with only central heating at ambient temperature 18 ° C. When there are two people, the energy saving rate is 3.1%. When the radiant power is 200W, at an ambient temperature of 14.5°C and there is only one person in the room using the device, the energy saving rate is 19.6%. When there are two people, the energy saving rate is 4.3%. When more than three people separately use the device for local radiant heating, the energy saving effect cannot be achieved. In practical applications, two or more people can share a radiant heating device for local heating of the backs. The room area is smaller, and the energy saving rate will be higher if the room area is larger.

| Temperature/°C | Heating Energy Consumption/W | Local Radiant Heating Power/W | Total Energy Consumption/W | Energy Saving Rate/% |
|---------------|-------------------------------|-------------------------------|---------------------------|---------------------|
| 12.5          | 668.69                        | 300                           | 968.69                    | 26.0                |
| 14.5          | 853.48                        | 200                           | 1053.48                   | 19.6                |
| 18            | 1309.47                       |                               | 1309.47                   |                     |
4. Conclusion
1) When the indoor temperature in winter cannot meet the thermal comfort of the human body, local radiant heating can significantly improve the thermal sensation.

2) The location of radiant heating has a direct impact on human thermal sensation. The backs have greater effect on the thermal sensation and thermal comfort than the ankles.

3) When the ambient temperature is 12.5℃ and the radiant power on the back of the human body is 300W, the TSV can reach 0.05. When the ambient temperature is 14.5℃ and the radiant power on the back of the human body is 200W, the TSV also reaches -0.2. The energy saving rate of the room with 300W local radiant heating at ambient temperature 12.5℃ is 26% compared with the room with only central heating at ambient temperature 18℃, and at ambient temperature 14.5℃ is 19.6%. When the number of people increases, the energy saving rate will be reduced. In practical application, two or more people can share one device to achieve the purpose of energy saving.

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References
[1] VESELý M, ZEILER W. Personalized conditioning and its impact on thermal comfort and energy performance-a review [J]. Renewable and Sustainable Energy Reviews, 2014, 34: 401-408
[2] OI H, TABATA K, NAKA Y, et al. Effects of heated seats in vehicles on thermal comfort during the initial warm-up period [J]. Applied Ergonomics, 2012, 43(2):360-367
[3] Edward Arens, Hui Zhang, Charlie Huizenga. Partial-and Whole-body Thermal Sensation and Comfortable-Part II: Non-uniform Environmental Conditions [J]. Journal of Thermal Biology. 2006, 31: 60-66
[4] ZHANG H, ARENS E, KIM D E, et al. Comfort, perceived air quality, and work performance in a low- power task-ambient conditioning system [J]. Building and Environment, 2010, 45(1):29-39
[5] ZHAI H, ZHANG H, ZHANG Y, et al. Comfort under personally controlled air movement in warm and humid environments [J]. Building and Environment, 2013, 65: 109-117
[6] PAUST W, ZHANG H, ARENS E, et al. Energy-efficient comfort with a heated/cooled chair: results from human subject tests[J]. Building and Environment, 2015, 84: 10-21
[7] Quan Jin, Lin Duanmu, Hui Zhang, Xiang Li, Hongbo Xu. Thermal sensations of the whole body and head under local cooling and heating conditions during step-changes between workstation and ambient environment [J]. Building and Environment, 2011, 46(11).
[8] Lv B, Chang S, Lei Y, et al. Effects of stimulus mode and ambient temperature on cerebral responses to local thermal stimulation: An EEG study [J]. International Journal of Psychophysiology, 2017, 113:17.
[9] AI-Ghamdi A, Mohammed S E A Ansari M J, et al. Comparison of physicochemical properties and effects of heating regimes on stored Apismellifera, and Apisflorea, honey [J]. Saudi Journal of Biological Science, 2017, 68:177-186.
[10] National Bureau of Quality and Technical Supervision. Measurement of PMV and PPD index in moderate thermal environment and regulations on thermal comfort conditions: GB/T 18049-2000
[11] HE Y, LI N P, HUANG Q. A field study on thermal environment and occupant local thermal sensation in offices with cooling ceiling in Zhuhai, China[J]. Energy and Buildings, 2015, 102:277-283.