Human Body Cooling Effect of Local Non-Isothermal Airflow during Natural Ventilation

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Abstract. In recent years, the natural ventilation system has been attracting attention not only as an energy saving method but also as a countermeasure method for COVID-19 in a building with poor ventilation. However, during natural ventilation, the outside air temperature has a large effect on the indoor environment, which causes fluctuations in the indoor thermal environment. In such a situation, it is effective to positively utilize the indoor airflow generated during natural ventilation as a method of utilizing the advantages of natural ventilation while maintaining the thermal comfort of the room. Most of the airflow generated by natural ventilation is non-isothermal airflow lower than room temperature, but there are few previous studies on non-isothermal airflow compared to isothermal airflow. In addition, in the actual measurement survey conducted by the author, it was found that the whole body does not receive the airflow uniformly during natural ventilation, but often receives the airflow locally such as the upper body. Therefore, the purpose of this paper is to clarify the effect of local non-isothermal airflow generated during natural ventilation to cool the human body. To achieve this goal, we conducted experiments with thermal manikin in a climate chamber. The amount of heat loss for each human body segments was measured under 28 conditions with clothes, room temperature, airflow temperature, and airflow velocity as parameters. As a result, the following findings were obtained.

Keywords. Natural ventilation, Thermal manikin, Local non-isothermal airflow, Thermal comfort sensation

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1. Introduction

Recently, the natural ventilation system has been garnering considerable attention, not only as an energy saving method, but also as a countermeasure method against COVID-19 in a building with poor ventilation. However, during natural ventilation, the outdoor air temperature has a significant effect on the indoor environment, which causes fluctuations in the indoor thermal environment. As an example, although the energy-saving and cooling effects of the outdoor air increase as the introduced outdoor air temperature decreases, there are cases where residents near the natural ventilation inlet may complain, thereby leading to the suspension of the natural ventilation operation [1]. In other words, from the perspective of saving energy, it is desirable to relax the outside air conditions that allow natural ventilation; however, the range is limited by the balance with indoor comfort. Therefore, it is important to operate natural ventilation considering the comfort of residents. In the survey of permit conditions for natural ventilation in actual buildings, there were few cases in which comfort was adopted as the permit condition [2].

Various standards and studies already exist on indoor airflow, and it is recommended to keep the still air in the room when operating mechanical air conditioning. The ASHRAE standard recommends that the indoor airflow should be less than 0.2 m/s to prevent cold drafts, and should not exceed 0.8 m/s even when the airflow can be adjusted [3]. However, it has been reported that when the room temperature is relaxed by Cool Biz in the summer or when the airflow temperature is not negligible, a positive feeling of comfort can be obtained by the airflow owing to the natural wind. Xing et al. [4] reported that the practical temperature decreases by 0.55 °C was owing to the increase in the airflow by 0.15 m/s on the surface of the human body in a hot environment. Several other studies have been conducted on isothermal airflow exposed to the entire body [5]. Although these studies are aimed at isothermal airflow that is uniform throughout the body, in an actual natural ventilation building, it is possible to obtain an airflow lower than room temperature that hits the human body locally (local non-isothermal airflow). It is necessary to accumulate further knowledge on such local non-isothermal airflow. In addition, several studies on the effects of natural wind on the human body are conducted by subject experiments, and only a few studies quantitatively evaluate the cooling effect of the human body under the condition of local non-isothermal airflow. Therefore, in this study, experiments were conducted using thermal manikins at various room temperature and airflow conditions under the natural ventilation of an actual building. Accordingly, the effect of cooling the human body by local non-isothermal airflow was quantitatively evaluated. Furthermore, subject experiments were conducted at temperatures of 22 °C and 29 °C to evaluate comfort.

2. Research methods

2.1 Experiment outline

This experiment was conducted in the artificial climate room of the Wind Engineering Research Centre, Tokyo Polytechnic University. An inverter fan was installed for airflow control in the artificial climate room, while a spot air conditioner and blowout temperature control were employed to generate airflow with varying wind speeds and blowout temperatures; in addition, the amount of loss at each part was measured using a thermal manikin.

Fig. 1 illustrates the plan and composition of the artificial climate chamber. Furthermore, Fig. 2 presents the cross sections of the artificial climate chamber, manikin installation position, and measurement position. Here, a box was installed on the suction side of the inverter control fan, while the outlet temperature was adjusted by mixing the cold air from the spot air conditioner with the outlet temperature control function and the room air in the box. Photo. 1 illustrates a case of the manikin and fan room in the artificial climate room. In addition, as illustrated in Photo. 2, The thermal manikin is installed sideways in a sitting position 2 m away from the inverter control fan, and one unit is located on the third stage from the floor (a 0.9-m height from the floor level). The measurement was performed under the condition that a local air flow was applied from the side to the upper body using a fan. Only the fans surrounded by the white frame in the photo were operated. Such measurement conditions reproduce the effects of the perimeter's occupants in a naturally ventilated building.

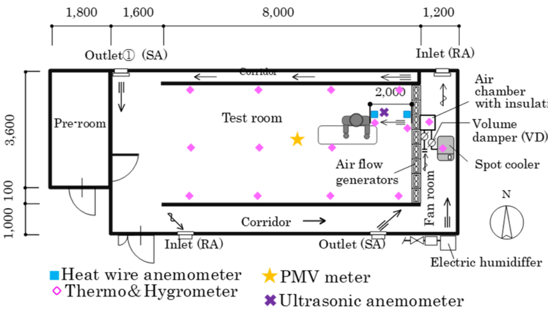


Fig. 1 Climate-controllable wind tunnel

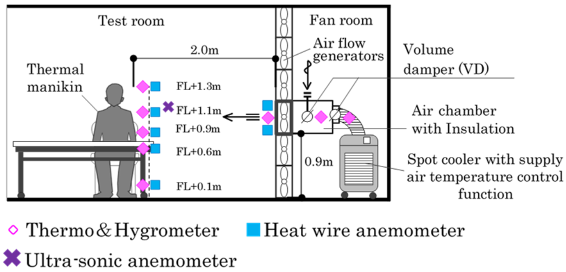


Fig. 2 Measurement points (sections)

(1) Thermal manikin in the chamber (2) Fan room

Photo. 1 Climate chamber experiment

2.2 Measurement condition

In this experiment, a thermal manikin manufactured by MTNW and an Asian male model were utilized. The manikin specifications and their measurement conditions are presented in Tables 1 and 2, respectively. The measurements were performed under the conditions of long-sleeved clothing at 22 °C, short-sleeved clothing at 29 °C, and long- and short-sleeved clothing at 26 °C. Photo. 3 presents an illustration of the clothes. The CLO value of the clothes were measured based on AIJES-H0005-2015 [6]; accordingly, 0.76 and 0.49 CLO values were obtained for the long and short sleeves, respectively. The thermal manikin was measured under 28 conditions by setting 4 conditions for the combination of room temperature and clothing, 3 conditions for wind speed, and 3 conditions for airflow temperature. The temperature of the thermal manikin was controlled to a constant temperature, and the set temperature was 33 °C, which was the skin temperature at the time of thermal neutralization by Gagge et al. [7].

2.3 Experimental procedure

The artificial climate chamber was sufficiently air-conditioned before commencing the experiment, the thermal manikin was preheated for 2 h or more, and the measurements started after the skin surface temperature was stabilized at 33 °C. The measurements were performed twice or more under one condition, and the average value obtained was calculated after verifying that the difference was negligible. Furthermore, to make the manikin's posture the same in each experiment, the positions in which the chair, desk, and manikin's hands were placed were marked, and the distance between each part of the manikin and chair or desk was measured beforehand.

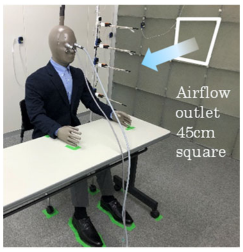
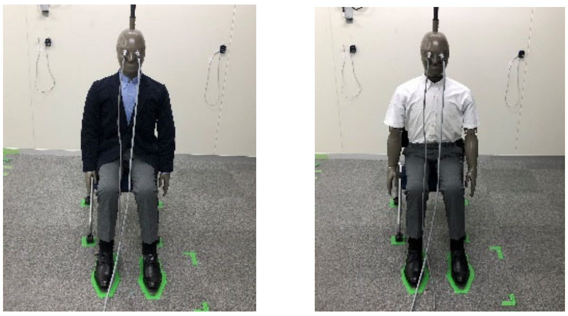


Photo. 2
Measurement position

Table 1 Thermal Manikin specifications

USA MTNW Corp. Newton 20-Zone Sweating Thermal Manikin	
Asian male model 168.5cm・30kg 20 divisions (face, head, chest, shoulders, back, stomach, upper arms, forearms, hands, hip, thigh, calf, foot) Total body surface area: 1.71m²	



(1) Long sleeve（0.76clo） (2) Short sleeve（0.49clo）

Photo.3 Clothing conditions

Table 2 Measurement Condition

Item	Set point	
Room temperature	22 °C, 26 °C, 29 °C	
Average radiation temperature	Operate the air conditioner until the average radiation temperature is equal to room temperature	
Relative humidity	40% RH	
Thermal manikin control	Constant skin surface temperature control (33 °C)	
Fan control conditions	Operate one fan in the third row from the bottom and the third row from the left, and perform measurements under three conditions: (1) Stop, (2) 0.6 m/s, (3) 0.8 m/s.	
Airflow temperature conditions	Airflow temperature was measured near the fan and the following three conditions were used: (1) isothermal (2) 2 °C lower than room temperature, (3) 4 °C lower than room temperature,	
Combination of room temperature and clothes	Room temp.: 22 °C/26 °C	Long sleeve clothing
	Room temp.: 26 °C/29 °C	Short sleeve clothing
Long-sleeve clothing	Pants, shirts, long-sleeved shirts, jackets, slacks, socks, and leather shoes	
Short-sleeve clothing	Pants, shirts, short-sleeved shirts, slacks, socks, and leather shoes	

3. Experimental results

3.1 Indoor thermal environment

In the experiment, the representative room temperature was controlled within the set room temperature of ±0.2 °C, while the relative humidity was controlled within the range of ±2%. Fig. 3 and 4 presents the results obtained from measuring the wind speeds and temperatures of FL + 0.1 m, 0.6 m, 0.9 m, 1.1 m, and 1.3 m from the floor, at a position 10 cm away from the manikin. According to the measurement results, the FL + 1.1 m and 1.3 m airflows, which are close to the height of the outlet, were the fastest in the isothermal airflow, while the FL + 0.6m airflow was the fastest in the non-isothermal airflow. The airflow velocity was slightly slower than the wind speed at the outlet. Regarding the distribution of the airflow temperature, it can be verified that the temperature of the airflow, which is 22 °C at the outlet, increases by approximately 2 °C near the manikin to 24 °C. Photo. 4 presents the results obtained from a laser visualization experiment on the changes in airflow properties due to airflow temperature. In the isothermal airflow, the airflow from the outlet moves straight and hits the shoulders and head; however, in the non-isothermal airflow, the turbulence becomes large and tends to hit the upper arm and armpit. Table 3 presents the results obtained from measuring the wind speed and the degree of turbulence at a height of 1.1 m near the manikin using ultrasonic wind speed. It can be observed that the isothermal airflow has a large average wind speed and a small degree of turbulence, while the non-isothermal airflow has a small average wind speed and a large degree of turbulence.

3.2 Whole body heat loss due to local non-isothermal airflow

Table 4 presents the results of the total heat loss of the thermal manikin for each case. The whole-body heat loss in each case ranged from 23.9 to 68.4 W/m². It was 40.1 W/m² in a still air at 26 °C (short sleeves), which appears to be close to the neutral state. When the airflow temperature was 4 °C lower than room temperature and the wind speed was 0.8 m/s, the systemic heat loss increased by 13.8 to 18.9 W/m² from the still air. It was also verified that the amount of heat loss can be adjusted between 5.9 and 11 W/m² by changing clothes from long sleeves to short sleeves.

Although the amount of heat loss in the entire body is suitable for comparing the cooling effect of each airflow pattern on the human body, it is impossible to directly evaluate the thermal sensation or comfort. Therefore, the whole-body equivalent temperature $t_{eq,whole}$ was obtained from the amount of whole-body heat loss using Equations (1) and (2).

$$t_{eq,whole} = t_{s,whole} - R_{t,cal,whole} \cdot Q_{t,whole} \quad (1)$$

$$R_{t,cal,whole} = \left(t_{s,cal,whole} - t_{a,cal}\right)/Q_{t,cal,whole} \quad (2)$$

SET* was calculated under the conditions of air temperature and average radiation temperature for the entire body, metabolism amount of 1.0 MET, cloth amounts of 0.76 CLO for long sleeves and 0.49 CLO for short sleeves, airflow of 0.1 m/s, and relative humidity of 50%. From the experiment, the thermal resistance values $R_{t,\ cal,\ whole}$ from the skin surface to the environment in the standard environment calculated using the Equation (2) were 0.166 m²K/W

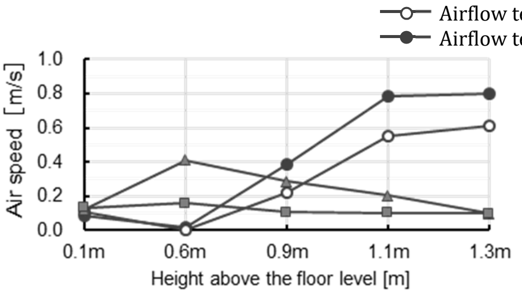


Fig. 3 Air speed distribution near the thermal manikin (Room temperature: 26 °C)

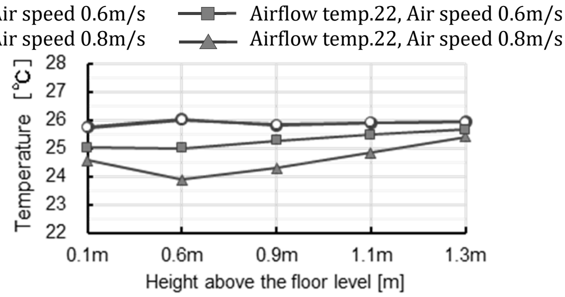


Fig. 4 Airflow temperature distribution near the thermal manikin (Room temperature: 26 °C)

(1) Low temperature airflow at 23 °C, Front

(2) Isothermal airflow at 26 °C,

(3) Low-temperature airflow at 23 °C diagonally forward

Photo. 4 Airflow visualization (room temperature: 26 °C, air speed: 0.8 m/s)

Table.3 Average air speed [m/s] and airflow turbulence [%]

Airflow temp, Wind speed	Room temp. 26℃		Room temp. 29℃	
Isothermal, 0.6m/s	0.52m/s	26.7%	0.40m/s	39.0%
Isothermal, 0.8m/s	0.79m/s	17.3%	0.73m/s	21.8%
Room temp.−2℃, 0.6m/s	0.40m/s	43.1%	0.31m/s	55.6%
Room temp.−2℃, 0.8m/s	0.55m/s	39.8%	0.56m/s	38.0%
Room temp.−4℃, 0.6m/s	0.19m/s	46.8%	0.18m/s	46.1%
Room temp.−4℃, 0.8m/s	0.31m/s	49.3%	No data	No data

Table.4 Whole body heat loss of thermal manikin

	Whole body heat loss [W/m²]			
	22℃ (Long sleeves)	26℃ (Long sleeves)	26℃ (Short sleeves)	29℃ (Short sleeves)
Still air	53.1	34.2	40.1	23.9
Isothermal, 0.6m/s	58.1	36.0	44.0	25.1
Isothermal, 0.8m/s	60.8	37.4	46.0	26.6
Room temp.−2℃, 0.6m/s	60.5	39.7	49.3	31.3
Room temp.−2℃, 0.8m/s	65.6	42.5	52.4	33.0
Room temp.−4℃, 0.6m/s	62.1	41.8	49.9	32.5
Room temp.−4℃, 0.8m/s	68.4	48.0	59.0	38.6

and 0.203 m^2K/W under the short- and long-sleeve conditions, respectively.

3.3 SET in local non-isothermal airflow*

Fig. 5 presents the whole-body equivalent temperature obtained from the whole-body heat loss under each experimental condition, while Fig. 6 shows SET*. It was demonstrated that SET* decreased by a maximum of 2.9 °C owing to the local non-isothermal airflow compared to the calm state at each room temperature. Fig. 7 presents the change in SET* when the blowout temperature and wind speed change by 1 °C and 1.0 m/s, respectively. The numerical value presented in the legend represents the rate of change of SET* obtained from the slope of the approximate straight line of the measurement data. From the results of (a) and (b), it can be observed that SET* decreases in the range of 0.19–0.58 °C when the airflow temperature is lowered by 1 °C. The decrease in the airflow temperature is particularly significant at a temperature of 29 °C, where the temperature difference from the skin surface temperature is negligible. It was deduced that when the wind speed was increased by 1 m/s in (c), SET* decreased in the range of 0.54–1.72 °C. At a temperature of 22 °C, the difference from the skin surface temperature was significant; hence, the rate of decrease in SET* tended to be large, and the rate of decrease in short-sleeve conditions with more exposed parts tended to be greater than that of long-sleeve conditions.

From the experimental results obtained by Xing et al., it is considered that when the wind speed on the surface of the human body increases by 1.0 m/s, the practical temperature drops by approximately 3.7 °C; however, in this experiment, it was 1.72°C. This difference is considered to be due to the difference in the exposure range of the airflow, and it can be deduced that the data of this experiment are obtained from the evaluation of the airflow during natural ventilation under conditions close to actual conditions.

3.4 Amount of heat loss by site

Fig. 8–11 present a comparison of the amount of heat loss by site. Fig. 8 shows the results of isothermal airflow while Fig. 10 presents the results of non-isothermal airflow 4 °C lower than room temperature. When the temperature of the room drops from 29 °C to 22 °C, the temperature difference on the skin surface increases, and the amount of heat loss at each site generally increases. At a temperature of 29 °C, the difference between parts is negligible; however, when the temperature of the room drops to

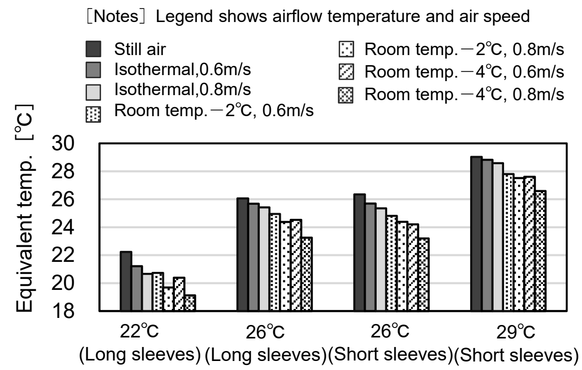


Fig. 5 Equivalent temperature

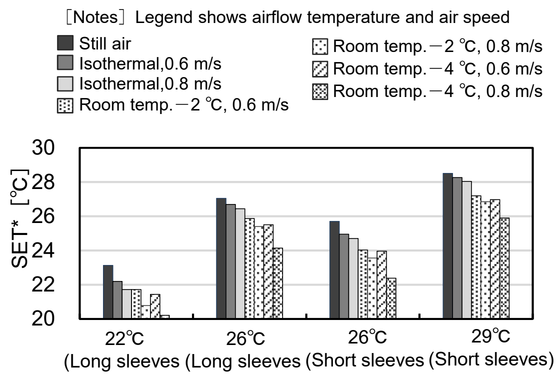
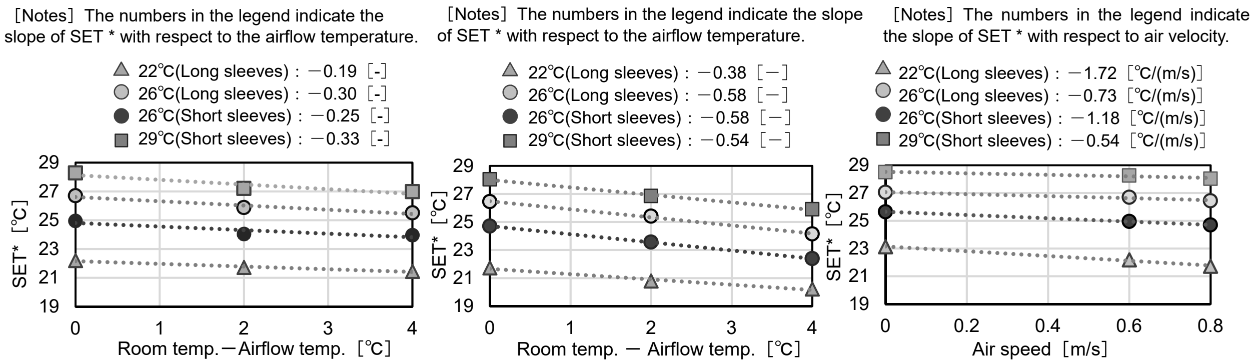


Fig. 6 SET* obtained from the equivalent temperature and room temp.



(a) Temperature difference and SET* (Air speed: 0.6 m/s)

(b) Temperature difference and SET* (Air speed: 0.8 m/s)

(c) Isothermal airflow speed and SET*

Fig. 7 Rate of decrease of sensible temperature due to airflow temperature and air speed

26 °C and 22 °C, the amount of heat loss in the undressed head, forearms, hands, and thighs increases. From Fig. 10, it can be observed that in non-isothermal airflow, the amount of heat loss in the upper and lower arms increases significantly when the clothes are changed from long sleeves to short sleeves.

Compared to the exposed parts of the upper body and the lower body, the chest, shoulders, stomach, back, and hip were less affected by the temperature of the room and airflow. It is expected that this is owing to the heat insulating effect of clothes and the difference in how the airflow hits the body. In addition, when the temperature of the room drops, the rate of increase in the amount of heat loss in the lower body becomes larger than that in the upper body parts such as the chest, shoulders, and abdomen. The reason for this is hypothesized to be the difference in heat insulation between the upper and lower body clothing and the heat plume of the human body.

Fig. 9 illustrates the relationship between the airflow temperature at a temperature of 29 °C and the amount of heat loss for each part. At a 29-°C temperature, which is close to the skin surface temperature, the cooling effect due to the air speed is negligible, while the cooling effect due to the airflow temperature is significant. As the airflow temperature decreases, the cooling effect of the lower body, such as the thighs, increases in addition to the exposed parts such as the upper arms and hands.

Fig. 11 presents the results of exposure to an isothermal airflow at a temperature of 22 °C and exposure to a non-isothermal airflow of 22 °C at a room temperature of 26 °C. Although the airflow temperature is the same as 22 °C, in an isothermal airflow with a room temperature of 22 °C, the airflow is less turbulent and is primarily exposed to the head; hence, the amount of heat loss on the head and face is significant. Conversely, in the non-isothermal airflow, the turbulence of the airflow is significant, and the part below the shoulder is cooled. In particular, under the short sleeve condition, the amount of heat loss in the arm part is substantial.

4. Comparison with subject experiments

4.1 Subject experiment outline

In the thermal manikin experiment, the effect of cooling the human body by the airflow during natural ventilation was demonstrated. However, it is necessary to verify the actual thermal sensation and comfort felt by subject experiments. Therefore, a subject experiment was conducted in an artificial climate room under the same conditions as the manikin experiment. The subjects included eight

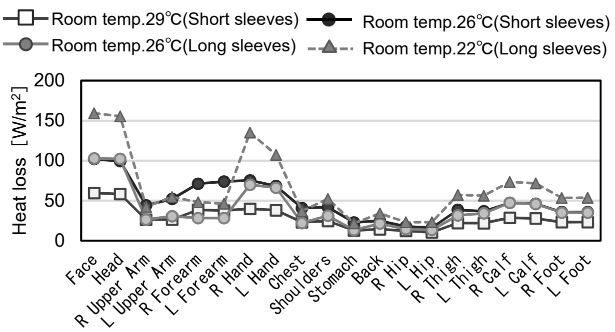


Fig. 8 Room temperature/clothes and heat loss by site (Air speed: 0.8 m/s, isothermal)

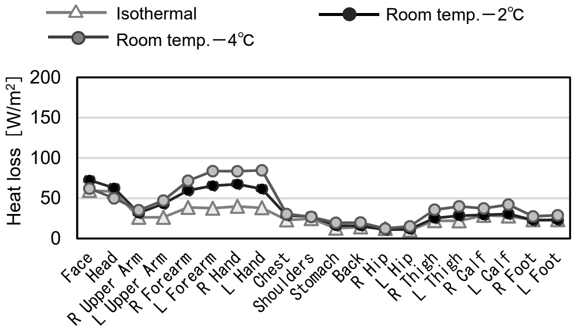


Fig. 9 Airflow temperature and heat loss by site (Room temp.: 29 °C, air speed: 0.8 m/s, short sleeves)

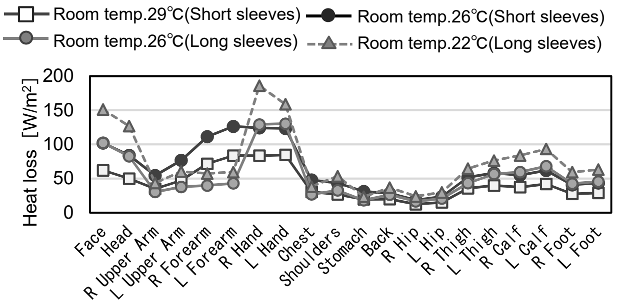


Fig. 10 Room temperature/clothes and heat loss at different sites (Air speed:0.8 m/s, room temp.: −4 °C)

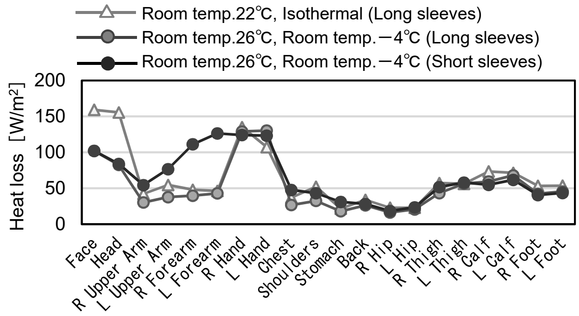


Fig. 11 Airflow temperature: 22 °C, air speed: 0.8 m/s, and heat loss at different sites

adult males, and the survey was conducted from September to October 2021. The experimental cases are presented in Table 5.

The room temperatures were 22 °C and 29 °C, while the relative humidity was 40%. However, for 29 °C, a case with a relative humidity of 70%RH was included. There were nine experimental cases in total, and eight subjects participated in all nine experimental cases. The state of the experiment is presented in Photo. 5, while the experimental procedure is illustrated in Fig. 12. Three cases of the experiments were conducted per day, and the subjects were asked to do step-up exercises during the experiments to maintain their metabolic rate at 1.2 MET. During the experiment of Case 1, the questionnaire on the feeling of warmth, coldness, and comfort was reported thrice. The three questionnaires were the same and attempted to verify the change in the subject's feelings over time. In the experiment, in addition to the questionnaire, the skin surface temperature of each part was also measured.

Table 5 Experimental cases

	Subject	Climate chamber		Air flow	
	Clothing [clo]	Room temp. [℃]	Relative humidity [%]	Air speed [m/s]	Air temp. [℃]
Case 1-1	0..49	29	40	0.8	29℃ (Isothermal)
Case 1-2					27℃(-2℃)
Case 1-3					25℃ (-4℃)
Case 2-1			70		29℃ (Isothermal)
Case 2-2					27℃(-2℃)
Case 2-3					25℃ (-4℃)
Case 3-1	0.76	22	40		22℃ (Isothermal)
Case 3-2					20℃(-2℃)
Case 3-3					18℃ (-4℃)

Table 6 Measurement condition of wet mode

Item	Set point
Set point of sweat flow (ml/min)	Head:53, Face:30, Upper Arm:8, Forearm:14, Hand:41, Chest:15, Shoulders:40, Back:73, Hip:60, Thigh:30, Calf:50, Foot:18
Thermal manikin control	Constant skin surface temperature control (33 °C)

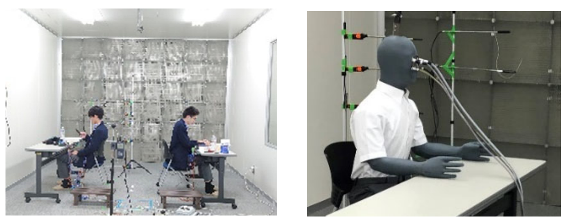


Photo. 5 State of the experiment

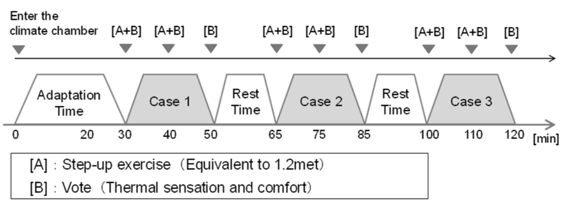


Fig.12 Experimental procedure

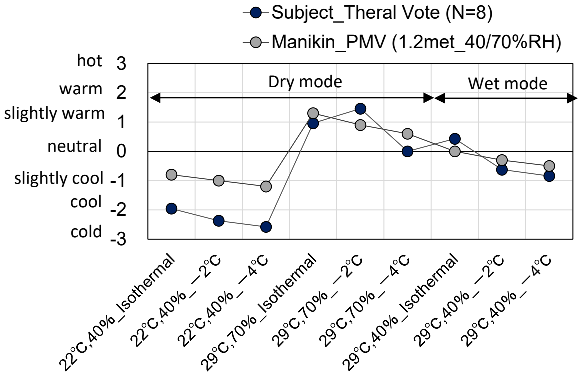


Fig. 13 Thermal sensation vote and PMV calculated from measurement data

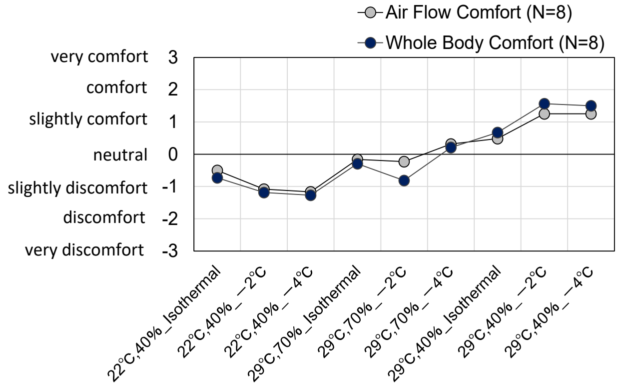


Fig. 14 whole body and airflow comfort

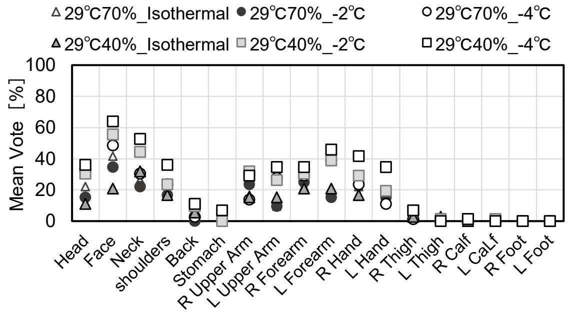


Fig. 15 The part where the subject feels the air flow (Room temperature 29℃)

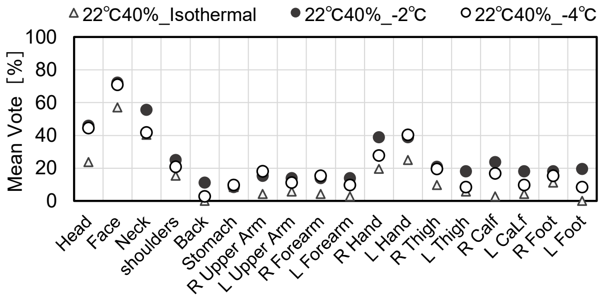


Fig. 16 The part where the subject feels the air flow (Room temperature 22℃)

4.2 Thermal sensation vote

Fig. 13 presents the results obtained from the thermal sensation vote report by the subject experiment. To compare the results of the subject experiment with the thermal manikin, the predicted mean vote (PMV) was calculated using the equivalent temperature obtained from the thermal manikin data. For the cases of 22 °C, 40%RH and 29 °C, and 70%RH, the amount of heat loss measured by the thermal manikin under dry conditions was adopted. In addition, at 29 °C and 40%RH, which are significantly affected by latent heat evaporation, the amount of heat loss was measured again with a sweating thermal manikin, and the obtained data were utilized. Photo. 5 and Table 6 present the measurement conditions for the sweating thermal manikin. The CLO value of the clothing including a fabric skin was calculated, and PMV was calculated from the equivalent temperature. PMV was calculated using the equivalent temperature of the entire body as the air temperature and average radiation temperature, and the metabolic rate was 1.2 MET, the amount of clothes was 0.76 CLO for long sleeves, 0.49 CLO for short sleeves, the indoor wind speed was 0.15 m/s, and the relative humidity was 40%. RH and 70% RH were adopted.

In addition, Fig. 14 presents the results of a questionnaire regarding whole-body and airflow comfort. At 29 °C (70% RH) the thermal sensation vote was slightly warm, and comfort vote was slightly unpleasant. The results were slightly cool and slightly comfortable under the conditions of 29 °C (40% RH). Under these conditions, the PMVs obtained from the amount of heat loss in the thermal manikin and the subject's thermal sensation vote were close to each other. At 22 °C (40% RH), the subject's vote was between cool and cold, which was slightly unpleasant. There was a significant difference between the results of the thermal manikin at 22 °C and 40% and the subject's vote, which is considered to be owing to the effect of local discomfort.

4.3 Airflow sensation by site

Fig. 15 and 16 present the results of the declaration regarding the part where the subject feels the air flow. At a room temperature of 29 °C, it can be observed that the head, neck, shoulders, and arms feel the airflow, centering on the upper body, because the clothes are short-sleeves. At a room temperature of 22°C, it was deduced that airflow was felt in the head, neck, hands, and lower body owing to the long-sleeved clothes. It is considered that the discomfort of the airflow related to these parts affects the whole-body warmth and discomfort at 22 °C. There was a difference in how the lower body felt the airflow between 29 °C and 22 °C. Fig. 17 presents the results of the requests for changes in the wind speed and temperature of the airflow. At a room temperature of 29°C, there were several requests to strengthen the airflow and reduce the airflow temperature; however, in a room of 29 °C and 40% RH, when the airflow temperature was at a room temperature of -4 °C, the ratio at which it was acceptable was the largest. At a room temperature of 22 °C, there were several requests to weaken the airflow and increase the entire airflow temperature.

4.3 Skin surface temperature

Fig. 18 presents the average skin surface temperature of the subjects. At a room temperature of 29 °C, the skin surface temperature was in the range of 32–35 °C, and the skin surface temperatures of the stomach and foot, which were not directly exposed to airflow, were slightly higher than those of other parts. There was also a tendency for the skin surface temperature of the upper arm and hand to decrease in low-temperature airflow compared to isothermal airflow. At a room temperature of 22°C, the temperature was in the range of 28–32 °C, and the skin surface temperatures of the Back of the hand and foot tended to be slightly low. The entire skin surface temperature appears to be generally low, which seems to affect the results of the subject's vote, slightly cold.

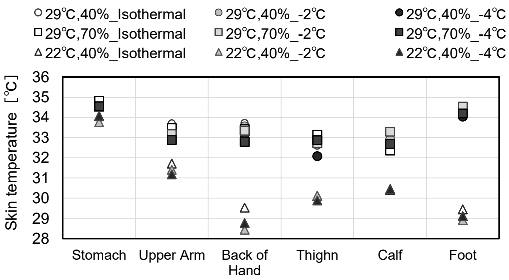


Fig. 18 Average skin surface temperature

5. Discussion

From the results of the subject experiment, it was inferred that the room temperature of 22 °C was cold and uncomfortable under the experimental conditions that reproduced the natural ventilation, and it appeared unsuitable as an indoor environment during natural ventilation where the indoor airflow is generated. In addition, although the airflow was centered on the upper body, the coldness of the lower body tended to increase. Furthermore, it was expected that the subject feels colder than the amount of cooling heat obtained by the thermal manikin, owing to local discomfort. However, it was confirmed that when the room relative humidity was low at a room temperature of 29 °C, positive comfort was obtained from the air flow. The room temperature range that allowed natural ventilation was generally in the range of 22–26 °C; however, if the airflow from the natural ventilation inlet can be utilized, a higher room temperature setting, such as 24–28 °C, should be adopted. It is assumed that this approach will provide comfort.

6. Symbols

$R_{t,cal,whole}$: Total cloting insulation[(m² · K)/W]
Short sleeves 0.166[(m² · K)/W],
Long sleeves 0.203[(m² · K)/W]

$Q_{t,cal,whole}$: Amount of sensible heat loss from the whole body under standard conditions [W/m²]

$Q_{t,whole}$: Amount of sensible heat loss from the whole body [W/m²]

$Q_{t,segment}$: Amount of sensible heat loss by site [W/m²]

$t_{eq,whole}$: Whole body equivarent temperature [°C]

$t_{s,whole}$: Skin surface temperature [°C] =33

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Data Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.