



# Research on the Environmental Thermal Comfort Based on Manikin

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**Abstract.** The subjective evaluation and objective test are the main methods to study the thermal comfort sensation of the environment. The Predicted mean votes (PMV) are calculated by thermal environment parameters obtained from the test points in general objective tests. However, the unstable factors of indoor environment make the description and prediction comprehensively and accurately impossible by the traditional methods. Through the physical and physiological characteristics of Chinese population in the Chinese adult human database, 50 percentile male adults' three dimensional physical data was selected to establish the manikin model. Controlling strategy was formulated according to the heat balance equation and thermal manikin test system was designed to test the exchanged heat between human body and environment in an unsteady and heterogeneous environment. In the specific heat and humidity environment created by the laboratory, the predicted mean vote (PMV) of the current environment was  $-0.8$  by the thermal manikin test system. At the same time, the subjective evaluation tests were conducted in the environment and the thermal sensation vote (TSV) was  $-0.65$ . The relative error was only 2.1% between the subjective evaluations and the objective test results of the manikin.

**Keywords:** Thermal comfort · Thermal manikin · Predicted mean vote  
Thermal sensation vote

## 1 Introduction

According to figures, we spend more than 80% time of our life indoors, in which the environmental qualities, like sound, light, thermal environment and air quality, all have a significant impact on our physical and mental health, comfort and work efficiency. Physiological research shows that in a comfortable thermal environment, it's good for thinking, observation and operation. The subjective and objective evaluation methods are always used to evaluate the thermal environment in the research. The results of the

subjective evaluation are usually discrete, which are obtained through the process and synthesis of the subjective evaluation scales. The subjective evaluation method can assess the comfort of the current environment intuitively and clearly. The objective evaluation is completed by the experiments, and the results are in good stability and consistency, which guarantees the results comparability and reproducibility even in different laboratories. Consequently, it is the main method to study the thermal comfort of the environment by the combination of subjective evaluation and objective test.

When it comes to the objective evaluation method, currently, the majority of researchers use the stable thermal environment created by an artificial climate chamber to get the evaluation. Indoor thermal environment parameters (air temperature, humidity, air velocity and average radiant temperature) are measured by the arranged measuring points, and the indoor thermal environment evaluation indexes, such as the predicted mean vote, the air vertical temperature difference value, temperature fluctuation and temperature uniformity, are led to give the thermal environment evaluation more comprehensively and objectively. But the actual indoor thermal environment is often unstable because of the numerous unstable factors, like the asymmetric radiation, the partial airflow and the partial cooling factor. Accordingly, it is difficult for the general thermal environment parameters to describe and predict the thermal comfort extent accurately in such environment. However, in unsteady conditions, the heat exchange between the human and the environment can be tested directly by the thermal manikin which is similar to human in the shape and it can predict the thermal comfort degree of the human. Through the manikin, the heat exchange process between the human body and the environment can be simulated and the thermal comfort can be evaluated scientifically. What is more, the effect of individual difference is avoided and the accuracy is ensured. So, it has been generally accepted that the thermal manikin is an indispensable method in the human body efficacy research.

Many foreign institutions have developed thermal manikin. In Finland, Ehab Foda et al. used thermal manikin that are based on skin temperature control method to test the thermal comfort and energy efficiency of the partial floor heating system, and the results were used to conduct the design of the system. In Hungarian, Edit Barna et al. found the warm floors and cold walls had combined effects on human thermal comfort during their research by thermal manikin. The results showed that the cold wall can reduce the partial average equivalent temperature of the hand and the face by  $2^{\circ}$ , and the vertical cold wall has much greater influence than the warm floor on the thermal comfort sense. In Swiss, Bogerd et al. used thermal manikin to study how the speed, head elevation, and hair condition affect the forced convection heat loss of a motorcycle helmet.

At Coimbra University in Portugal, Oliveira et al. made a comparative study on the heat loss between the static and dynamic posture of the thermal manikin in the natural convection and the forced convection condition. The result showed that in natural convection condition, the average convective heat transfer coefficient of the static body was about  $3.5 \text{ W/m}^2\cdot\text{K}$ , while the dynamic body was about  $4.5 \text{ W/m}^2\cdot\text{K}$ . In Singapore, Cheong et al. used thermal manikin with independent heating control method in the 26 sections to study the thermal comfort of the human in the displacement ventilation room with different temperature distributions. The result showed that the partial thermal discomfort in the cold was more obvious than the warm. In France, Elabbassi et al.

studied the effect of electric blanket on the dry heat loss of the newborn body by thermal manikin. Matsunaga et al. evaluated the thermal comfort in the vehicle by combining the thermal manikin test with numerical simulation and subjective experience.

Nowadays, most thermal manikins in research institutions were based on European and American people's physiological characteristics instead of Chinese. So, it has been imperative to develop and build the thermal manikin system based on Chinese people's physiological characteristics to evaluate the thermal comfort of the environment objectively. In this thesis, the manikin model was established through the 50 percentile male adults' three dimensional physical data from the Chinese adult human database. Controlling strategy was formulated according to the heat balance equation and thermal manikin test system was designed to test the exchanged heat between human body and environment in an unsteady and heterogeneous environment. And the feasibility of the test system to evaluate the environment was verified through subjective evaluations and objective experimental tests.

## 2 The Physical Model of Thermal Manikin

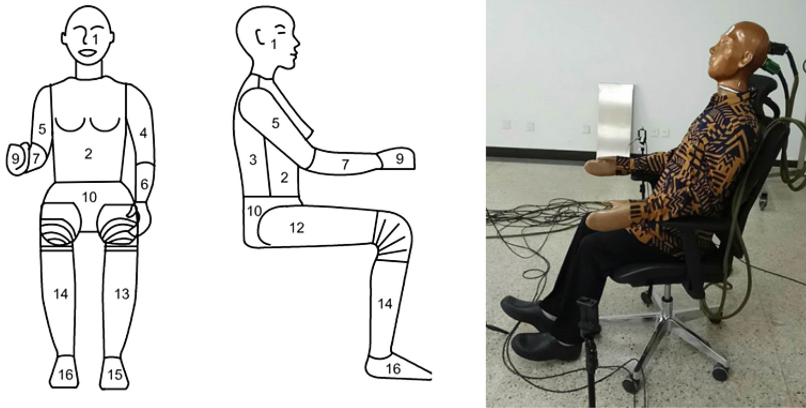
The thermal manikin was designed according to the 50 percentile China's male adults' physical data, including 16 independent control sections, such as the head, the left upper arm, the right upper arm, the left forearm, the right forearm, the left hand, the right hand, the chest, the back, the hip, the left thigh, the right thigh, the left leg, the right leg, the left foot and the right foot. There were active joints, like the hip, the knee, the elbow and other joints. It included standing and sitting posture. The heating of each area in the manikin was controlled individually by low voltage power and the temperature sensors were arranged to measure the surface temperature. There were various sensors in the regions with different heat transfer conditions, like the legs, the torso, the hips, etc. The heat flow and surface temperature of each region were measured and controlled by a computer. The manikin's structures and partitions are shown in Fig. 1. Its main joints can be adjusted, and the posture can be adjusted according to the measured demand.

## 3 The Control Principle of the Thermal Manikin

The manikin is controlled according to the heat balance equation in the comfortable condition of human body, and its surface temperature depends on the heat exchange between the body and the surrounding environment. Without considering the external work of the human body, the heat balance equation in the comfortable condition is as follows:

$$M = Q_t = Q_{res} + E_s + Q \quad (1)$$

$$Q_{res} = 1.7 \times 10^{-5} M(5867 - P_a) + 0.0014 M(34 - t_a) \quad (2)$$



**Fig. 1.** The sections of the thermal manikin partition and the entire structure

$$E_s = 3.05 \times 10^{-3}(5733 - 6.99M - P_a) + 0.42(M - 58.15) \tag{3}$$

In the formula:  $M$  is the metabolic heat production of body ( $W/m^2$ );  $Q_t$  is the total heat transfer between the body and the environment ( $W/m^2$ );  $Q_{res}$  is the respiratory heat exchange of the body, ( $W/m^2$ );  $E_s$  is the evaporative heat exchange of the skin ( $W/m^2$ );  $Q$  is the convection and radiant heat transfer between the body and the environment ( $W/m^2$ );  $P_a$  is the partial pressure of the vapour in the environment, taken as 1500 Pa;  $t_a$  is the air temperature, taken as 20°C.

From the above three formulas, the relationship of the total heat dissipation ( $Q_t$ ) and the convection radiation heat transfer ( $Q$ ) between the body and the environment is as follows:

$$Q_t = 1.96Q - 21.56 \tag{4}$$

In comfortable conditions, the relationship between the average superficial skin temperature ( $t_{sk}$ ) and total heat dissipation ( $Q_t$ ) is as follows:

$$t_{sk} = 35.77 - 0.028Q_t \tag{5}$$

From the above two formulas, the following formula can be got:

$$t_{sk} = 36.4 - 0.054Q \tag{6}$$

This formula is the controlling equation to adjust the manikin’s surface temperature. The surface temperature of the manikin depends on the heat dissipation to the environment and the heating power of the manikin. According to the heating power of each region ( $Q_n$ ) and the surface temperature ( $t_{sk,n}$ ) of its different regions, the equivalent space temperature ( $t_{eq,whole}$ ) of the manikin can be calculated.

## 4 The Experimental Environmental Conditions

Because the indoor environment test is to simulate the home environment, the experimental room were built, including a bed.

The test procedures and matters are as follows:

- (1) Before the testing, the thermal manikin and its clothing thermal resistance should be calibrated in the laboratory environment. After calibration, the position and dressing cannot be changed.
- (2) In order to avoid the influence of wall heat accumulation in the environmental comfort test, the wall should be preheated for a period to ensure its temperature reaches the specified value.
- (3) In the test, the thermal manikin and environment parameters are used to evaluate the thermal comfort at first, and then the subjective thermal comfort evaluation of the test participants is carried out in the same environmental conditions.

In the outdoor environmental simulation: The Table 1 shows the outdoor environmental conditions of the air conditioner thermal comfort evaluation laboratory. After the operation of the tested air conditioner, the ambient temperature and humidity of the outside room shall conform to the specified requirements in Table 1. When the thermal comfort technology of the manikin is under experiment, the outdoor environment should be in the summer condition.

**Table 1.** Laboratory operating conditions.

Environmental parameters	Refrigeration condition (in summer condition)
Outdoor dry-bulb temperature (°C)	35 ± 0.5
Outdoor wet-bulb temperature (°C)	24 ± 0.5

The average indoor temperature of the experiment was 24.1 °C. In the test, the clothes of the manikin included a single vest, spring or autumn shirts, underwear, spring trousers, thin socks and single layer shoes. Calibration test of clothing thermal resistance was conducted before test and the result was 0.58 col. In the verification test of the thermal comfort test, the thermal manikin was adopted sitting posture, and the participants sat quietly or did some mild activities, like reading. The intensity was 1.2 Met.

## 5 The Experimental Process

The manikin was located in the center of the room. After the environmental parameters being stable, thermal manikin was used to evaluate the thermal comfort of the air conditioning environment. After the test output of the test system steadily, the thermal comfort evaluation results of the current environment can be obtained.

Subjective experimental process:

- (1) The participants wore the lab clothes in a room and then enter the experiment room.
- (2) The experimenter explained the test procedures and matters to the participants, and more attentions were paid to the method of judging the thermal sensation for the participants' suitable and accurate judgment.
- (3) Let the participants adapt the environmental conditions. Observed the indoor air temperature and the black globe temperature by the temperature testing system. After the stability of the relative data more than 5 min, the participants were informed to make the first subjective sensation evaluations. After 10 min, 15 min, 20 min, 25 min, 30 min, 45 min, 60 min, 75 min, 90 min, subjective sensation evaluations also needed to be taken.

Attention: Participants must be in the same position as the manikin.

24 participants were selected, and they are adult male from 20 to 50 years old, which the specific age distribution are in the Table 2. Because of the relationship

**Table 2.** The age distribution of the participants

20–29 years'old	30–39 years'old	40–49 years'old
8	12	4

between the thermal comfort sensation and body mass index (BMI), the participants' BMI are counted in Table 3.

Before the test, participants changed the summer clothes and adjusted themselves in the setting outdoor environment more than 30 min. During the time, referring to the thermal comfort subjective test table, the test assistant who was in charge of the test, introduced the test process, and informed the participants what they need to record during the test. Results were taken by 7 levels scoring system to describe the thermal sensation, which is in Table 4.

## 6 The Experiment Results

The results of the 24 participants' test data were processed and the thermal sensation of the human body in the summer environment varied for the time they spent indoors, as shown in Fig. 2:

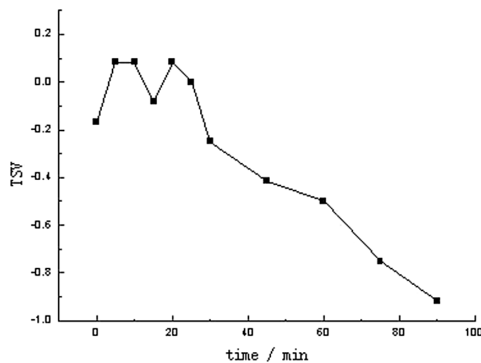
Because the outside temperature was 35°, participants felt comfortable and cool when they entered the room. As time went on, most participants still felt comfortable within 30 min, and the average thermal sensation vote of the 12 participants fluctuated within  $\pm 0.2$ . With the increase of the indoor time, the overall heat sensation of the participants came into being cool after 30 min, and the average TSV began to decrease gradually. That is because of the experimental requirements. The participants were engaged in meditation, reading or other mild activities in the a bit cooler environment, so

**Table 3.** The BMI distribution of the participants

Slightly thinner <18.5	Normal 18.5–23.9	Slightly heavier 24–27	Obesity 27.1–32	Extremely obesity >32
0	12	8	4	0

**Table 4.** 7 levels of the thermal sensation

Cold	Cool	Slightly cool but comfortable	Comfortable	Slightly hot but comfortable	Slightly hot	Blazing
-3	-2	-1	0	1	2	3



**Fig. 2.** The change of whole-body thermal sensation with time in the test environment

the longer they spent, the cooler sensation they would have. Over 90 min, the average TSV of the whole body had dropped to  $-0.92$ . According to the ISO14505 which regulates the ergonomics of the thermal environment, the subjective test results of thermal comfort experience should be stemmed from the participants coming into the environment 30 min to 90 min. According to this regulation, the environmental thermal comfort of the test was calculated and the average thermal sensation vote was  $-0.65$ .

The thermal manikin was used to evaluate the thermal comfort of current environment and the results can be seen in the Fig. 3.

In the Fig. 3, about one hour after the beginning, the equivalent space temperature and the predicted mean vote (PMV) of the manikin tend to be stabilized. When the test system is stable, the average equivalent space temperature of the body is about  $22^{\circ}$ , and the PMV is about  $-0.8$ . Comparing the test results about the predicted mean vote with the subjective evaluation test, the relative error is only 2.1% between the subjective evaluations and the objective test results of the manikin, which demonstrates that thermal manikin can be used to test the thermal comfort of the environment accurately.

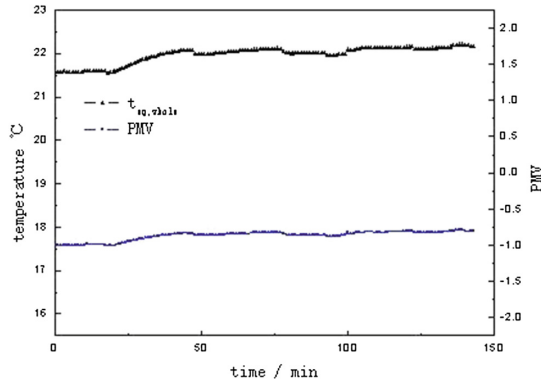


Fig. 3. The test results of the environmental thermal comfort by the manikin' evaluation.

## 7 Conclusions

Through Chinese adult human body database, 50 percentile male adults' three dimensional physical data was selected to establish the thermal manikin physical model. The control strategy was formulated according to the heat balance equation of the human body under the comfortable condition and a thermal manikin test system was designed to test the exchanged heat between human body and environment in unsteady and heterogeneous thermal environment. Creating a specific heat and humidity environment in an artificial environment laboratory, test the predicted mean vote (PMV) of the current environment by using the thermal manikin test system, which was  $-0.8$ . At the same time, the subjective evaluation tests were conducted in the environment and the thermal sensation vote was  $-0.65$ . The relative error was only 2.1% between the subjective evaluations and the objective test results of the manikin, which demonstrates that thermal manikin can be used to test the thermal comfort of the environment with various merits, like convenient operation and high accuracy.

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