Analysis Skin Temperature Distribution of Thermal Manikin

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Abstract. Thermal Manikin is a human model designed for research and development in outdoor and indoor, military, and clothing environmental experiments. This research aimed to analyze the skin temperature distribution from Thermal Manikin. This study used Thermal Manikin which functions as a representative of the human body where the surface temperature of the body Thermal Manikin is made close to the surface temperature of the human body. The temperature of the Manikin Thermal skin was made constant at 34°C ± 1°C under stable room temperature conditions. Experiment was carried out with various air temperature conditions from 26°C to 32°C. Skin temperature measurements carried out on 24 body parts of Thermal Manikin for 90 minutes at 1-minute intervals. The measurement results obtained was then compared and analyzed at various air temperature conditions. The results of the analysis showed that the temperature of the skin in each part of the body's thermal Manikin was evenly distributed in each part of the body and the temperature of the body's skin thermal Manikin increases with the increasing air temperature around thermal Manikin.

1. Introduction
Thermal Manikin is a human model designed for scientific experiments in the thermal environment. Thermal Manikin has been used for research and development for more than 90 years. The use of Thermal Manikin can reduce the risk of errors in human trials. Thermal Manikin is usually used in indoor and outdoor, military and clothing environmental experiments. [1]. Thermal Manikin has 3 main elements, namely outer skin, heating element, and sensor [2]. According to Nilsson, A.L that the human body removes or transfers heat to the surrounding environment in 4 ways, namely radiation, convection, conduction, and evaporation. Skin temperature is one of the important measurement parameters in determining heat loss from the body surface. Environmental factors such as temperature, relative humidity, and air velocity can affect skin temperature [3].

Based on research conducted by Wigo, H & Nilsson, H about the application of Thermal Manikin to evaluate heat loss from humans caused by air velocity and air temperature. In this study, the Thermal Manikin used is set to be constantly close to the human skin temperature of 34°C in every part of the body [4]. Based on research conducted by Quintela, D, et al about the analysis of heat transfer from Thermal Manikin. In this study, Thermal Manikin Maria made of fiberglass which is coated using wire throughout the body to be heated so that heat transfer analysis can be carried out by convection and radiation when standing, sitting, and lying down. Thermal Manikin Maria has 16 body parts that are regulated by skin temperature independently [5]. Based on research conducted by Kurazumi, Y et al about the coefficient of heat transfer by convection and radiation to the human body...
in natural or free convection conditions. In this study, Thermal Manikin used has movable joints on the shoulders, hips, and knees. Thermal Manikin is divided into 17 body parts where each body part is regulated at a constant skin temperature at 33°C [6]. Based on research conducted by Richard, J. d Dear et al about the coefficient of heat transfer by convection and radiation for each part of the human body. This study uses Monika Manikin Thermal which has 16 body parts with each body part having a fiberglass material with a thickness of 4 mm which is coated with 0.3 mm nickel wire for heating [7]. Based on research conducted by Yehu, Lu, et al about thermal insulation produced by clothing is determined on the moving Thermal Manikin. In this study, Newton's Thermal Manikin is used to have 34 body-zone zones in which each body part can be individually regulated body surface temperature and a thermocouple sensor is installed to store data using ThermDAC software [8]. Based on research conducted by Tong, X, et al about experimental evaluation of the characteristics of heat and humidity transmission from hot coal mine work clothes using Thermal Manikin. In this study, Newton's Thermal Manikin 20-zone body part where each part of the body has a heating and sensor system independently and has a sweat skin system that is regulated using an external water pump [9].

Thermal Manikin is designed to maintain temperature stability in the body so that the temperature of the Thermal Manikin skin can resemble the temperature of human skin. The surface temperature of the Thermal Manikin skin is 34°C which is close to the temperature of human skin under stable thermal conditions. The measurement zone on the thermal manikin used by Fotjlin, M et al is 34-zone thermal manikin, namely the head, neck, left and right upper arms, left and right forearms, left and right hands, chest, abdomen, waist, left upper thigh and right, left and right lower thighs, left and right calf, left and right foot. [10].

The human body in this study used Thermal Manikin as a representative of the human body that is made to resemble the temperature of the human skin. Thermal Manikin is made by installing copper wire inside it in a floating state to be heated using electricity from a 24V, 30A power supply and spread using a fan, then the heat is regulated in such a way that the surface temperature of the bead skin is kept stable at around 34°C under stable thermal conditions. The zone of thermal measurement of Manikin measured in this study were 24-measurement zones, namely the head, neck, chest, abdomen, left and right upper arms, left and right forearms, left and right thighs, left and right calf.

2. Method
This is an action study research on the distribution of the skin temperature on thermal manikin. The stages carried out in this study are started from the study of literature and preliminary studies then formulation of the problem. Data collection is done to be used as input in research. Data processing is performed by comparing the temperature of the skin of each body part of the thermal manikin. Then the problem-solving analysis is carried out to get conclusions and suggestions for further research.

2.1. Experiment Facilities
The study was conducted at the Climate Chamber of Ergonomics and Work System Design Laboratory, Faculty of Engineering, Industrial Engineering, Universitas Sumatera Utara, Medan. The Climate Chamber is in a closed room with carpet all over the room so that it is airtight, and the roof is coated with a ceiling and has one Air-Conditioning (AC) of 2 PK. The Climate Chamber is set to have stable conditions where the room temperature ranges from 26°C ± 0.1°C, air velocity <0.2 m / s, and relative humidity 50% ± 10%. The object of research observed was Thermal Manikin. Thermal Manikin as a representative of the human body where the surface temperature of the body Thermal Manikin is made close to the surface temperature of the human body in general. Thermal Manikin was made from a fiber-based manikin that is mounted with copper wire inside the body in a floating position supported by both bolts on the left and right to be heated using a current flow from a 12V, 30A power supply and controlled using a heat controller. The heat generated from copper wire was then distributed using a fan or a small fan in the body so that air can spread throughout the body. Thermal Manikin was coated using a copper conductive paint coated with silver with a surface
resistance of $\Omega 0.3\Omega / 10\text{cm}$ to all parts of its body, which functions as a conductor that can conduct electricity or heat so that the heat is spread evenly in all parts of the body.

2.2. Data Collection
The temperature of the Thermal Manikin skin is set at a stable condition which is equal to $34^\circ\text{C} \pm 1^\circ\text{C}$. Thermal Manikin was divided into 24 parts as shown in Figure 1. Thermal Manikin was controlled using a heat controller and the skin temperature is measured for each part of the body using sensors that are equipped with the Arduino program to measure and store the measurement results by sending it to the PHPMyAdmin database. The measured skin temperature was then analyzed.

![Figure 1. Measurement Body Parts of Thermal Manikin](image)

The following is a description for each body part of the Thermal Manikin measurement which can be seen in Table 1.

| No | Body Parts            | No | Body Parts                 |
|----|-----------------------|----|----------------------------|
| 1  | Front Head            | 13 | Upper Left Upper Arm       |
| 2  | Front Neck            | 14 | Right Upper Upper Arm      |
| 3  | Chest                 | 15 | Left Rear Forearm          |
| 4  | Stomach               | 16 | Rear Right Forearm         |
| 5  | Back head             | 17 | Front Left Thigh           |
| 6  | Back of the neck      | 18 | Front Right Thigh          |
| 7  | Upper Back            | 19 | Front Left Calf            |
| 8  | Lower Back            | 20 | Front Right Calf           |
| 9  | Upper Left Upper Arm  | 21 | Left Left Thigh            |
| 10 | Upper Right Upper Arm | 22 | Right Back Thigh           |
| 11 | Front Left Forearm    | 23 | Left Back Calf             |
| 12 | Forearm Right Front   | 24 | Right Back Calf            |
Measurement of skin temperature data on Thermal Manikin is measured in various conditions of air temperature, namely changes from 26°C, 28°C, 30°C, 32°C. Measurements were carried out for 90 minutes at intervals of 1 minute each.

2.3. Analysis
Analysis is carried out by using statistical data of each measurement on every temperature change. These data were then formed into a graphs to obtain the linear line and its tendency and its influence on the manikin. All of these graphs then compared to find out the uniformity of the overall results. If the graphs show similar pattern for each temperatures, then the manikin is adequate to be used as experimental object. If not, then additional adjustment needed to be done.

3. Result and Discussions
3.1. Results
Measurement of the temperature of the Thermal Manikin skin was carried out by placing sensors on each part of the body Thermal Manikin. These measurements were given a variety of treatments namely varying air temperatures ranging from 26°C, 28°C, 30°C, 32°C. The following is a comparison chart of skin temperatures for each part of the body under various conditions of air temperature which can be seen in Figures 3,4,5,6 and 7.
As shown in Figure 3 that the skin temperature for each body part Thermal Manikin at an air temperature of 26°C shows the distribution of skin temperature between 33°C-35°C. Based on the linear line of $y = -0.011x + 34.036$ shows that the data is decreasing on each body parts of Thermal Manikin.

![Figure 4](image)

**Figure 4.** Comparison of Skin Temperature Graph For Each Body Part of Manikin Thermal at 28°C Air Temperature

As shown in Figure 4 that the skin temperature for each body part Thermal Manikin at an air temperature of 28°C shows the distribution of skin temperature between 33°C-36°C. Based on the linear line of $y = 0.0089x + 34.487$ shows that the data is increasing on each body parts of Thermal Manikin.

![Figure 5](image)

**Figure 5.** Comparison of Skin Temperature Graph For Each Body Part of Manikin Thermal at 30°C Air Temperature
As shown in Figure 5 that the skin temperature for each body part Thermal Manikin at an air temperature of 30°C shows the distribution of skin temperature between 34°C-37°C. Based on the linear line of \( y = 0.0093x + 35.629 \) shows that the data is increasing on each body parts of Thermal Manikin.

![Figure 6](image)

Figure 6. Comparison of Skin Temperature Graph For Each Body Part of Manikin Thermal at 32°C Air Temperature

As shown in Figure 6 that the skin temperature for each body part Thermal Manikin at an air temperature of 32°C shows the distribution of skin temperature between 35°C-38°C. Based on the linear line of \( y = -0.0022x + 36.977 \) shows that the data is decreasing on each body parts of Thermal Manikin.

### 3.2. Discussion

The results shown in Figure 3 to Figure 6 then compared to find out the main pattern. There comparison is done to find out wether the canges on each part is uniform or not on each temperature changes. The comparison for each temperature is shown in Figure 7.
Based on Figure 7 with various air temperatures shows that each increase in air temperature causes the skin temperature to rise. This indicates that every increase in air temperature from a temperature of 26°C to 32°C causes an increase in skin temperature in every part of the body Thermal Manikin. The distribution temperature of the skin in each part of the body Thermal Manikin from various air temperature shows that skin temperature has been distributed equally.

4. Conclusion
The conclusions obtained based on the results and discussion that have been carried out at each temperature of 26°C, 28°C, 30°C, and 32°C indicate that the skin temperature has been distributed evenly. The comparison of each air temperature shows that every increase in air temperature causes an increase in skin temperature in every part of the body Thermal Manikin. The uniformity effect of this experiment showed that the manikin is adequate as the representative of human body and can be used in related experiment.

5. References
[1] Holmér I 2004 European Journal of Applied Physiology vol 92 p 614-618
[2] Holmér I 1999 Proc. 3rd Int. Meeting on Thermal Manikin Testing October 12-13 (Sweden) p 1–8
[3] A L Nilsson 2004 Journal of Investigative Dermatology vol 88(5) (Linkoping: The Society for Investigative Dermatology, Inc) p 586–593
[4] H Wigö and H O Nilsson 2016 Int. J. Vent. vol 3(3) p 219–225
[5] D Quintela, A Gaspar, and C Borges 2004 European J. Applied Physiology (Coimbra: SpringerLink) vol 92(6) p 663–668
[6] Y Kurazumi et al 2008 Building and Environment vol 43(12) (Japan Elsvier) p 2142–2153
[7] J R De Dear, A Edward, and D Ph 1997 Int. J. Biometeorol vol 40 (Berkeley: University of California) p 141-56
[8] Y. Lu, F. Wang, X. Wan, G. Song, W. Shi, and C. Zhang 2015 Int. J. Biometeorol vol 59(10) (Suzhou: SpringerLink) p 1475–1486
[9] X Tong et al 2017 Int. J. Heat and Technology vol 35(4) (Beijing: International Information and Engineering Technology Association) p 836–842
[10] M Fojžin, F Jan, J Miroslav 2016 Experimental Thermal and Fluid Science vol 77 (Brno: Elsvier) p 257-264

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