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THE EFFECT OF HUMAN BODY SURFACE AREA ON THERMAL COMFORT OF UNIVERSITY STUDENTS

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ABSTRACT

The study aims to analyze the effect of the Body Surface Area (BSA) on the thermal comfort of university students. The study involved a survey to collect the weight, height, and body temperature of respondents. The survey also collected the respondents' thermal response to their environment. The survey was carried out at the Faculty of Engineering, Khairun University, Ternate, and North Maluku Province, Indonesia. A total of 180 students, from the age of 20-25 years consisting of 143 men and 37 women have participated in this study. However, 30 students are excluded from the analyses due to their body temperature exceed 37.2 °C. Generally, the women body size is relatively larger than the man. The average weight and height for adult males are 60 kg and 164.62 cm, and females are 63 kg and 158.97 cm. The average body temperature of males was 36.7 °C and females was 36.25 °C. Most of the respondents (more than 80%) felt either warm or hot. There is a linear correlation between the Body Surface Area (BSA) and the thermal sensation vote (TSV) of respondents. Respondents with larger size of body surface tend to feel hotter than the ones with smaller size of body surface.

Keywords: Human skin, Body surface area, Thermal comfort, Students
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1. INTRODUCTION

The area of the human body (Body Surface Area) has long been considered as one of the important elements in the study of thermal comfort. BSA is a very important parameter in several ways, including in knowing the quality of the body's physiology, determination of drug dosages, estimation of burns, and studies in the mechanism of body heat transfer [1]. In preparing the recommendations referred to, the physical description and habits of life of the community groups are the basis. For this reason, it is necessary to develop a human concept of reference based on data collected in groups from the Caucasus race. The problem that arises is the difference in the size of the human body between Indonesian humans and human references from the Caucasus race proposed by ICRP (International Commission on Radiological Protection) [2]. This difference has been found by Rao [3] in India and Tanaka et al. [4] in Japan. Indian and Japanese studies have been supported by Dang et al. [5]. Dang et al. found that the bodyweight of the population in the two countries is very different from the Reference Man proposed by the ICRP [2]. This difference might be due to genetic and geographic differences.

Bodyweight is one of the parameters in kilograms (kg) used for body measurements (World Health Organization Expert Committee) [6]. Through weight can be known various information to analyze the condition of a person's body such as the Body Surface Area (BSA) and Body Mass Index (BMI) [7]. Mosteller formula for BSA in children and the Du Bois and Du Bois formula (Verbraecken, et al) [8].

Besides BSA, a person's body condition can be seen from BMI. BMI contains information on the structure of the human body in the form of an index from the calculation of the weight and height of a person [9].

Various factors affect the dimensions of the human body, including:

1. Age, the size of the human body will develop from birth to approximately 20 years old for men and 17 years for women. Then humans will decrease in body size when humans are 60 years old.
2. Gender, general, men have larger body dimensions except for the chest and hips.
3. Work, daily work activities also cause differences in the size of the human body.

1.1. Measurement of Human Body Surface Area

Various calculations have been proposed for BSA without direct measurement. In the following formula, BSA is expressed in m2, weight (or, more precisely, mass) W in kg, and height H in cm. The most widely used formula is the Du Bois and Du Bois formula [10] which is just as effective in estimating body fat in obese and non-obese patients, something the body mass index fails to do. Du Bois and Du Bois formula is expressed in the Eq. 1 as follows:

$$BSA\,(m^2) = 0.007174 \times H\,0.725 \times W\,0.425 \quad (1)$$

Mosteller formula is also commonly used in the BSA calculation [11]. The formula is expressed in Eq. 2 as follows:

$$\text{BSA}\ (m^2) = (\text{Height} \times \text{Weight}\ /3600)^{1/2} \quad (2)$$

1.2. Thermal Comfort

Determination of room temperature is also closely related to the measurement of the area of the human body. In terms of the study of air systems related to this matter known as thermal comfort. Thermal Comfort is a condition where the human mind feels satisfied or in accordance with the temperature of the surrounding environment (AHSRAE standard 55) [12]. Human reaction to higher temperature tolerance depends on his expectations, personality, and work at a certain time [13]. ASHRAE Standard used Fanger [14] formula to quantify the thermal sensation of respondents. The condition of the surveyed classrooms shows a hot, hot environment. Indoor air temperatures range from 30.5 °C to 33.8 °C with an average of 31.4 °C, which has exceeded the thermal comfort zone as specified in ASHRAE 55 standard [12]. Students' responses to thermal sensations give a number, where more than 70% votes in the center option (to +2 to +3). More respondents are expected to choose warm and hot.

The PMV/PPD model was developed by P.O. Fanger using heat-balance equations and empirical studies about skin temperature to define comfort. Standard thermal comfort surveys ask subjects about their thermal sensation on a seven-point scale i.e. cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (1), warm (2), and hot (+3). Fanger's equations are used to calculate the Predicted Mean Vote (PMV) of a group of subjects for a particular combination of air temperature, mean radiant temperature, relative humidity, airspeed, metabolic rate, and clothing insulation [14]. PMV equal to zero is representing thermal neutrality, and the comfort zone is defined by the combinations of the six parameters for which the PMV is within the recommended limits ($-0.5<PMV<+0.5$)[12]. Although predicting the thermal sensation of a population is an important step in determining what conditions are comfortable, it is more useful to consider whether or not people will be satisfied.

To predict how many people are dissatisfiesd in a given thermal environment, the PPD-index (Predicted Percentage of Dissatisfied) has been introduced. In the PPD-index people who vote -3, -2, +2, +3 on the PMV scale are regarded as thermally dissatisfied [12]. However, the use of Body Surface Area (BSA) to analyze the thermal comfort of human is not common in Indonesia. Most of thermal comfort studies in Indonesia were based on the thermal environment parameters i.e. air temperature, relative humidity, radiant temperature, and air velocity. The operative temperature which is a combination of air temperature and radiant temperature was commonly used to assess the thermal comfort of respondents [15-18].

This is a preliminary research that aims to analyze the effect of Body Surface Area (BSA) on the thermal comfort of university students. Specifically, the objectives of this study are as follows:

1. To investigate the Body Surface Area (BSA) of respondents in comparison to the Reference Man proposed by ICRP.
2. To investigate the thermal sensation of respondents in the university classrooms and the effect of gender on the thermal sensation votes (TSV).
3. To develop a thermal comfort model based on the Body Surface Area (BSA) of respondents.

2. MATERIALS AND METHODS

2.1. Research Sample and Respondent

The survey has been carried out in the Faculty of Engineering, Khairun University, Ternate City, North Maluku Province. Sample object its men and women in good health and do not have chronic illnesses or inherited physical or mental disabilities (this is known by asking respondents directly). Age of respondents 20-25 years. Parameters research is weight, height,

and body temperature. Measurements have been carried out using instruments such as body scales, meter, and Hand-held Thermal Imaging Camera. The survey has been carried out during April 2019.

To obtain the thermal sensation of students, questionnaires have been distributed to all respondents using survey method. The questionnaire was adapted from Wong and Khoo [19]. The questionnaire consisted of seven questions, which included thermal sensation votes (TSV), thermal comfort votes (TCV), thermal preferences, and respondents' thermal acceptance. In addition to the location of the building direction, the questionnaire was also intended to obtain respondents' perceptions of air temperature, air velocity, air velocity preferences, the humidity in the classrooms. TSV response was measured according to the ASHRAE 55 standard, which uses a seven-point scale to measure respondents' thermal sensations. Thermal comfort was also measured by asking respondents' thermal preferences and acceptance. A total of 180 students, from the age of 20-25 years consisting of 143 men and 37 women have participated in this study. However, 30 students are excluded from the analyses due to their body temperature above 37.2 °C.

2.2. Research Instrumentation

This research was conducted using several instruments. Infrared thermal imager that can blend the visible and infrared images, HOBO UX 100-003 temp/Relative Humidity for measuring air temperature and relative humidity, in the classroom.

Table 1 The specification of instruments used in the surveys.

Item	Specifications
Infrared thermal imager	Infrared Thermal Imager that can blend the visible and infrared images. Resolution of Infrared Image 3600 pixels. Resolution of Visible Image 0.3 megapixels. Range of Temperature Measurement -20 °C to +300 °C. Accuracy of Temperature Measurement ±2 % or ±2 °C (±2 % or ±4 °F.
Body Scale	Weight accuracy 2.0 kg – 40.0 4 sensor accuracy technology Automatic On / Off function Able to hold up to 150 kg Metric kg (kilograms) / lb (pounds) / st (stones) to choose from Display precision up to the nearest 100g increase
HOBO UX 100-003	Range: -20° to 70°C (-4° to 158°F) Accuracy: ±0.21°C from 0° to 50°C (±0.38°F from 32° to 122°F) Resolution: 0.024°C at 25°C (0.04°F at 77°F) Response time: 4 minutes in air moving 1 m/s (2.2 mph) Drift: <0.1°C (0.18°F) per year

2.3. Data Collection

Survey and questionnaire methods have been conducted to obtain primary data. Data collection is carried out as follows:

1. Objective data collection is carried out using the HOBO Sensor tool to measure environmental data mounted at 100 cm above the floor surface [13,20].
2. Subjective measurements are carried out to measure the respondent's thermal comfort level. Using a questionnaire technique, which was adapted from Wong and Khoo and has been used in previous research by Hamzah who is also the author of this paper [14, 20]. The questionnaire included seven questions, which captured the sound of thermal sensation (TSV), the sound of thermal comfort (TCV), thermal

preferences and thermal acceptance of respondents. In addition to air temperature, the questionnaire was also intended to obtain respondent data about air velocity, air velocity and class room humidity. Questions to respondents about favored things about thermals are related to the question What do you feel comfortable in this room. In addition, questions related to air velocity and humidity were also included in the questionnaire (Table 2).

Table 2 Thermal comfort questionnaire adapted from [15,19] used in the surveys.

1. Where is your class orientation?

North	South	East	West	NE	NW	SE	SW

2. How do you feel about the thermal environment in the room (thermal sensation)?

Cold	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot

3. What do you feel comfortable in this room?

Too cold	Comfortable and cold	Comfortable	Warm comfortable	Too Warm	Hot

4. At what level of temperature does this place satisfy?

Very satisfied	Satisfied	Not satisfied	Very dissatisfied

5. At present what do you want with the condition of the air / wind flow in this room?

Less air	No changes	More air

6. What do you feel about the humidity in this room?

Very too dry	Very dry	Somewhat dry West	Feels comfortable	A little moist	Very moist	Very too humid

7. Is the thermal environment acceptable

Yes	No

2.4. Data Processing and Analyses

Data analyses involved several methods including the use of computer software i.e. Microsoft Excel (MS Excel) and SPSS (Statistical Package for Social Science). MS Excel was used to analyze the data collected from the survey and presented in the table and graphical format. The SPSS was used to analyse the t-testand the regression between BSA and TSV.

3. RESULTS

The results of the study were analyzed based on the data gathered from a survey that involved 180 university students. The average body temperature of the respondents measured was 36.12

°C. A total of 180 students, from the age of 20-25 years consisting of 143 men and 37 women have participated in this study. However, 30 students are excluded from the analyses due to their body temperature above 37.2 °C. Normal body temperature varies by person, age, activity, and time of day. The average normal body temperature is generally accepted as 98.6 °F (37 °C). Some studies have shown that the "normal" body temperature can have a wide range, from 97 °F (36.1 °C) to 99 °F (37.2 °C). A temperature over 100.4 °F (38 °C) most often means you have a fever caused by an infection or illness [20]. At the time of survey and measurement, the indoor air temperatures range from 30.5 °C to 33.8 °C with an average of 31.4 °C, which has exceeded the thermal comfort zone as specified in ASHRAE 55 standard [12].

4. DISCUSSION

4.1. Calculation of Body Surface Area

Data on the size of the skin surface area of the average male and female students between the ages of 20-25 years. From Table 2 it is known that the size of the surface area of the skin of men is generally larger than women. For ages 20-25 years the size difference is quite noticeable. The bodyweight of women is 3.14% to 5.55% bigger than men, while their height is 1.5% to 6.76% smaller than men. Thus, the difference in body weight is greater than the difference in body height, because many factors determine a person's body weight such as nutrition, incoming calories, physical activity, heredity, geography and climate [4].

The results of Body Surface Area calculation using the formula Du Bois and Du Bois (Eq. 1) and Mosteller (Eq. 2). Table 3 shows that the surface area of a male body, for the age group of 20-25 years, is greater than - female. With increasing age, the surface area of the body gets larger because the weight and height of the body also increase with age. For all ages, the surface area of the Indonesian human body is 0.13% to 12.32% lower than that of the Caucasus.

Table 3 Average Size of Body Surface Area with Using Du Bois and Du Bois Formula (Eq.1), and Mosteller Formula (Eq. 2).

Gender	Height (cm)	Weight (kg)	Eq. 1 (m^2)	Eq. 2 (m^2)
Male	164.46	66.47	1.72	1.74
Female	159.93	64.68	1.72	1.70
Ave.	163.55	66.11	1.72	1.73

If the weight and height of the adult human body in Indonesia (Ternate) are compared to other Asian countries, the difference does not seem so great. However, when compared with the human reference ICRJP or African and American countries, the difference is quite large. The difference in body weight was greater than the difference in height, both with African and American countries and with the ICRP [2]. This shows that there are fundamental differences in size between Caucasus humans and Asian humans so that the compilation of skin surface area for students aged 20-25 years for Asia is important because it concerns the body's functional ability to release heat into the surrounding air for thermal comfort, and the level of accuracy of the air conditioning load allocation. If the weight and height of the Indonesian human body (150 student respondents in Ternate). by age is compared to the reference human weight and height proposed by ICRP [2] using 13,327 respondents, it appears that the size of Eastern Indonesian people is smaller than the ICRP (Table 4). This is clearly seen for ages over 20-25 years. The difference in male body weight and height is relatively greater than the difference for women.

Table 4 Comparison of the Size of the Weight and Height of the Ternate with ICRP Standard 23 (Age Between 20-25 years).

Location/ Standard	Height (cm)		Weight (kg)	
	Male	Female	Male	Female
Male	170.00	160.00	70.00	60.00
Female	164.46	159.93	66.47	64.68

Adult Caucasus humans are relatively different from Ternate humans. This might be relating to the amount and quality of nutrition consumed in addition to differences in residence and environmental conditions. By knowing the differences between Indonesian (Ternate) people and Caucasus people, there will be differences in the Body Surface Area of the skin owned by a person or community member.

Table 5 Body Surface Area (BSA) of the Skin.

BSA (m^2)	Male		Female	
	Students	%	Students	%
1.4	2	1.33	0	0.00
1.5	17	11.33	3	2.00
1.6	25	16.67	6	4.00
1.7	48	32.00	16	10.60
1.8	27	18.00	5	3.33
1.9	1	0.67	0	0.00
Total	150	80.00	30	20.00

Table 5 shows the distribution of respondents based on their Body Surface Area. The BSA is range from 1.4 to 1.9 m^2. The distribution of BSA follows normal distribution. The biggest BSA of male and female students were 1.9 and 1.8 m^2, respectively. The majority of students (either male or female) have BSA of 1.7 m^2 with total 62 students or 42.6%.

4.1. Thermal comfort of students

Thermal comfort is the number of calories produced by each body so that it affects the body temperature when indoors activities. A questionnaire was distributed to students to evaluate their thermal perception, while measurements were taken. The questionnaire was divided into three sections such as personal data, thermal aspects, and comfort level.

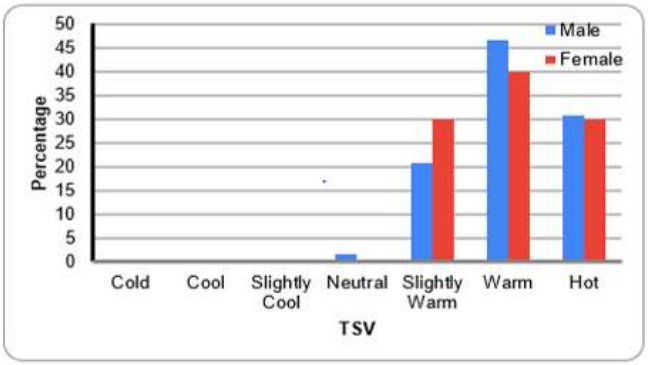

Figure 1 TSV of Male and Female Respondents.

Figure 1 illustrates the comparison of thermal sensation votes (TSV) between male and female. As shown in the figure, there were only two respondents voted neutral (0), while the majority of respondents voted in the hot area (warm and hot). Interestingly, no female felt neutral (0).

Overall TSV results of respondents' choice to warm up to 68 people or 45.33% which is the most choices and the choice of feeling the heat in the room is 46 respondents or 30.67%. Based on the ASHRAE Standard, almost 75% of respondents are dissatisfied with their thermal environments [16]. This was indicated by almost 75 % of respondents vote either warm (+2) or hot (+3), which are regarded as dissatisfied.

As seen in Figure 1, there were no significant differences in TSV between male and female respondents. These differences have been analyzed by the t-test statistical software. The results of t-test analysis are shown in Table 6. In comparison to the t table and the calculated t0.425 and the Sig. 0.811 confirmed that there was no significant difference in TSV between males and females.

Table 6 The results of t-test analysis.

Difference	Sig.	t	df
Male-Female	0.811	0.425	148

Table 5 shows the number and percentage of respondents' acceptance of their thermal condition of classrooms. The survey question is whether the thermal environment is acceptable or not for respondents. As seen in Table 5, there was a similar percentage of male and female respondents on their acceptance of thermal environment conditions in the classrooms. There were 26.7% and 33.3% of male and female accepted classrooms' thermal conditions. Most of the respondents have voted in the "No Acceptance" group, which accounted for 73.3% and 66.7%, for males and females, respectively. This acceptance rate is higher than allowed by ASHRAE Standard 55, which is a maximum of 20% of respondents do not accept the rooms' thermal environments.

Table 7 Percentage of Students' Acceptance of the Thermal Environment.

Acceptance	Male (%)	Female (%)
Yes	26.7	33.3
No	73.3	66.7
Total	100	100

Based on the TSV and thermal acceptance of respondents it can be concluded that most of the students do not satisfy by their thermal environments of classrooms in this surveyed university.

4.2. The effect of Body Surface Area on students' thermal comfort

The measurement of the average skin temperature of the human body can reflect the thermal comfort degree of the human body to some extent. For the average skin area of male and female respondents, the average is 1.72 m² based on calculations from Du Bois and Du Bois formula. From the total respondents for the calculation of the area skin can be seen in Table 4. With a surface area of the skin, 1.72 m² in the survey results stated that respondents felt uncomfortable in the room at that time.

Figure 2 illustrates the scatter plot between the BSA and the TSV. The figure also shows a linear regression line between BSA and TSV. According to the regression line, the BSA affects the students' TSV. The is a positive correlation between BSA and the TSV. The regression line indicates that the greater the area of the Body Surface Area (BSA) the respondents feel more uncomfortable.

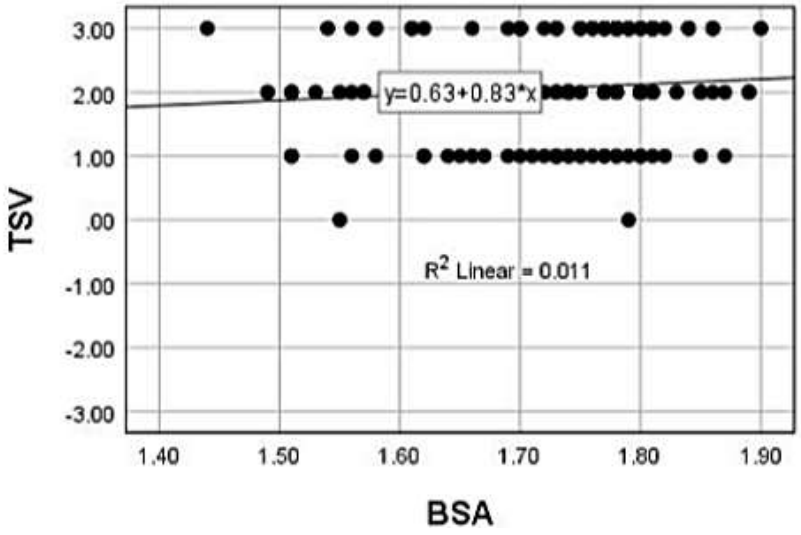

Figure 2 Relationship between Respondents' Thermal Sensation Vote (TSV) and Body Surface Area (BSA)

5. CONCLUSIONS

The average weight and height for adult males are 60 kg and 164.62 cm, and females are 63 kg and 158.97 cm. The average body temperature of males was 36.7 °C and females was 36.25 °C. Thermal comfort survey results show most of the students felt uncomfortable, where almost 80% of respondents voted either warm (+2) or hot (+3). Interestingly, there are only about 1% of those who voted neutral (0). This confirms that the air temperature in the classroom is hot, most students feel uncomfortable. In fact, 72% of respondents did not accept this thermal condition. There is a linear correlation between the Body Surface Area (BSA) and the thermal sensation votes (TSV) of respondents. Respondents with larger size of body surface tend to feel hotter than the ones with smaller size of body surface.

This study shows that in the tropical city of Ternate, students feel uncomfortable in the classroom especially when the room temperature is around 33.8 °C. The authors acknowledge that this study has involved a small number of data. It was also covering a small area of Indonesia and collected in a short time. Therefore, further research should be carried out before we can make conclusion of the effect of BSA on the thermal comfort of university students in naturally ventilated classroom in Indonesia.

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AUTHOR CONTRIBUTIONS

All authors contributed equally to this paper.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

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