Body fat rate and human thermal comfort relativity study with BIA in HVAC condition

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Abstract. The paper aims to study the correlation between human body fat percentage (BF), human body muscle percentage (BM) and thermal comfort in conditioned environments. With the body fat meter which uses the principle of bioelectrical impedance analysis (BIA) to determine individual's body fat and body muscle percentage and both TSV questionnaire and skin temperature to assess thermal comfort, the study considered the both whole-body thermal comfort and parts-of-body thermal comfort in indoor cooling condition. The result shows that there is a significant relationship between the BF and individual thermal comfort as lean people are less sensitive to the cold condition. Meanwhile, the leg part has max fat-comfort relativity, as there is a linear relationship between leg BM/BF and corresponding skin temperature.

Keywords: Body fat percentage, Body muscle percentage, BIA, Thermal comfort

1. Introduction

While air condition systems are widely used these days, people notice that even in the same temperature, different people may have different feelings. For example, it is likely for thin people to feel cold when strong people are enjoying the suitable thermal environment under the same setting of an air conditioner. Thus, many researchers began to study the factors affecting human thermal comfort, there are always two kinds of factors: external and internal parameters. Figure 1 shows the typical external and internal parameters:

Cause external parameters are easily be controlled, they are always taking into consideration. For instance, Alahmer [1] investigated the effect of relative humidity inside the vehicle to thermal comfort during the heating and cooling periods. Huang [2] found that the different air velocity and turbulence intensity were related to cooling infect.

Meanwhile, for internal parameters, metabolic rate is considered as an import factor. Luo [3] concerned the influence of thermal conditions on occupants' metabolism regulation through a chamber experiment, Choi [4] mainly focused on heart rate, the study revealed that heart rate has the potential to be used as an index to illustrate the human thermal sensation. Besides, it has been confirmed that the one of the
most important thermo-physiological differences between individuals result from body fat, and it influences both conduction heat transfer and blood flow. Different types of tissues require different amounts of blood, and fat, for example, requires less blood than muscle [5]. While the subject’s heart rate seems to react more sensitively to his/her high level of activity rather than his/her thermal sensation by the ambient thermal conditions [6]. Hence, body fat rate may be suitable for describing individual differences in thermal sensation.

In previous study, Nishimura [7] tested skin temperature of two group of subjects with different percentage of body fat (10.7±0.6% and 19.4±6.3%), result showed a decrease in skin temperature resulting from a body fat increase. Chudecka [8] found that the higher body fat mass has lower skin temperature but higher rectal temperature than the lean body fat group. But in those studies, most of papers prefer to just focus on skin temperature rather than consider subjects’ thermal satisfaction directly; Moreover, the factors they studied, including body fat mass, and muscle percentage were usually calculated by typical formulas instead of using other measure ways. Also, in the study, particle body fat and related thermal comfort are seldom taking into consideration.

This project aims to measure the body fat and muscle mass and percentages with the Bioimpedance analysis (BIA) body fat meter of people in different body fitness (including whole body and different part of body), and test participates skin temperature and thermal satisfaction in different thermal condition in order to study the relevance between body composition and human thermal comfort in conditioned environment.

2. Experiment Devices

2.1. BIA Body fat meter
Bioelectrical impedance analysis (BIA) is commonly used for estimating body composition, and in particular body fat. Since the advent of the first commercially available devices in the mid-1980s the method has become popular owing to its ease of use.

BIA determines the electrical impedance, or opposition to the flow of an electric current through body tissues which can then be used to calculate an estimate of total body water (TBW). TBW can be used to estimate fat-free body mass and, by difference with body weight, body fat. BIA is considered reasonably accurate and convenient for estimating percent body fat values, it is likely that there was no significant difference among the %fat values estimated by BIA (mean=20.6%) and DXA Scan(mean percent fat value of IF and SF was 23.3% and 22.6%, respectively)[8].

The study chooses OMRON 701. The combination of handheld and scale electrodes take into account both the upper and lower body when %BF is estimated. It is also able to test the BMI, visceral fat, muscle and fat ratios in the arms, legs and torso Basal metabolism.

2.2. TSV questionnaires
TSV(Thermal Sensation Vote) questionnaires are used to collect individuals’ thermal feelings. The questionnaire was divided into two parts, including mean thermal feeling (for whole body) and body part thermal feeling (arm, leg and trunk). The thermal sensation voting values are set according ASHRAE 7-point scale (-3:cold, -2:cool,-1:slightly cool, 0: neutral, +1:slightly warm, +2 warm, +3 hot).

2.3. Other Devices
Besides the body fat meter, other devices are also used in this test including Tape-measure, Temperature Sensor and Thermostatic chamber. Tape-measure is used to test individuals’ height, which will be used as an input parameter in the body fat meter. The thermostatic chamber will be used to simulate uniform thermal condition in the fixed temperature and humidity.

3. Experiment Design
3.1. Environment Parameter determination

According to Hong Kong Government’s suggestion, the indoor air conditioner temperature should be set to 25.5°C. But from the related study in Hong Kong indoor temperature set point, it is likely that the indoor air temperature is always set below 25.5°C which is always near 20°C. Thus, the chamber temperature is set for about 20°C and 25.5°C (RH =40% fixed air velocity=0).

3.2. Experiment Process

In this experiment, we will involve 8 participants including 4 males and 4 females graduated students from age 21 to 25. Each of them is in great health. Before testing BF, Participants will be asked to refrain from exercise and caffeine on the day of testing, not eat a heavy meal three hours prior to measurement and remove all jewellery and garments down according to manufacturer’s guidelines. When the test began, the participants are asked to take off the shoes and make foot get in contact with 4 electrodes, after their weight is tested with the weightier, they are asked to hold the 2 hand electrodes tight and make arms at ninety-degree angles with trunks for about 20 seconds.

In the period, all participants should wear light weight long pants and short sleeve T-shirts(clo=0.57). The indoor condition parameter will be set before the test begin. At the beginning, participant will have 10 minutes to accommodate the temperature, then their thermal feeling will be tested with the TSV questionnaire during the experiment. Every single experiment will last 30 minutes, and the participants will be asked to fill the TSV questionnaire for every 5 minutes. Meanwhile, human’s skin temperature will be tested with thermal imager. 5 points of human skin temperature are test, including face, chest, abdomen, forearm, hand and leg.

The mean skin temperature will be calculated with Burton’s formula (1934).

\[ T_{sk} = 0.5 \times T_{chest} + 0.36 \times T_{calf} + 0.14 \times T_{forearm} \]  

Figure 2. Body parameter and skin temperature measurement

4. Result Analysis

The detail parameter is listed in Table 1:
Table 1 Body parameter of all the participates

| Gender | Age | Weight | Height | BF_mean/BM_mean | BF_arm/BM_arm | BF_leg/BM_leg | BF_trunk/BM_trunk |
|--------|-----|--------|--------|-----------------|---------------|---------------|-------------------|
| 1 M    | 25  | 73.7   | 177    | 17.5/35.7       | 17.6/40.1     | 16.9/52.9     | 11.1/29.6         |
| 2 M    | 22  | 53.8   | 175    | 9.3/39.0        | 12.2/43.7     | 10.6/56       | 5.0/34.4          |
| 3 M    | 23  | 68.9   | 175    | 18.9/34.9       | 19.6/40.2     | 18.9/52.1     | 11.6/28.6         |
| 4 M    | 22  | 62.7   | 174.5  | 14.8/36.6       | 16.3/41.8     | 15.3/53.8     | 8.9/31.0          |
| 5 F    | 21  | 60.2   | 170    | 25.5/28.7       | 37/30.9       | 33.4/40.9     | 17.8/23.2         |
| 6 F    | 23  | 46.7   | 157    | 26.5/26.9       | 38.5/31.7     | 33.3/37.7     | 17.7/22.5         |
| 7 F    | 23  | 45.2   | 156    | 29.3/26.0       | 41.4/31.0     | 35.1/36.6     | 19.3/21.9         |
| 8 F    | 24  | 54.4   | 160    | 24.8/28.2       | 36.1/31.5     | 32.7/40.9     | 17.7/22.9         |

In the test, the mean BF of males are from 9.3~17.5, and the mean BF of female is from 24.8~29.3. In order to consider both human body fat issue and body muscle issue, the study use body muscle to body fat ratio which can describe total body composition as the variable. Due to the difference between male and female thermal comfort, the figure divided the result separately:

Figure 3. Mean skin temperature and TSV in 20°C and 25.5°C set point

There is the trend that people with higher body muscle to fat ratio will have higher mean skin temperature and higher TSV index in 20°C, which means that they will feel more comfortable in lower conditioned temperature. But in 25.5°C, the trend went less obvious.

Meanwhile, the correlation of thermal feeling of different body part are also considered.

- Arm

Figure 4. 20°C and 25.5°C set point BM_arm/BF_arm relevance with skin temperature and TSV
In this part, individuals’ forearm thermal sensation and the ratio of arm muscle to fat are analysed. According to the test, there is a trend that the people whose BM_{arm}/BF_{arm} between 2~2.5 has the higher arm skin temperature, and with the increasing of muscle to fat ratio, there is a slight decline of the forearm temperature. The trend is quite same in the TSV_{arm} result.

- **Leg**

![Figure 5](image1.png)

**Figure 5.** 20°C and 25.5°C set point BM_{claf}/BF_{claf} relevance with skin temperature and TSV

By using leg skin temperature as a factor here, from the figure, with the increasing of the BM_{leg}/BF_{leg}, in 20°C, participants’ leg temperature is increasing, and the correlation is quite obvious which can be illustrated with quadratic unary equation as follow, the $R^2$ is 0.8012.

$$y = 0.0354x^2 + 0.3679x + 30.056$$  

(2)

While in the 25.5°C, the correlation will be less significant.

- **Trunk**

In the experiment, we test the both chest temperature and abdomen temperature. The temperature of trunk will be calculated with following formula:

$$T_{TRUNK} = \frac{(T_{CHEST} + T_{ABDOMEN})}{2}$$  

(3)

![Figure 6](image2.png)

**Figure 6.** 20°C and 25.5°C set point BM_{trunk}/BF_{trunk} relevance with skin temperature and TSV

From the figure, the temperature of trunk is less related to muscle of fat ratio maybe due to the contribution of organs heat generation.

5. **Conclusion**

From the experiment and the analysis above, there are following conclusions:

- The BIA meter may be a suitable method to deal with the human body parameter in thermal comfort.
• It is likely that people with low mean body muscle to body fat ratio will feel more comfortable in lower temperature.
• There seems to be obvious correlation between leg temperature and BM/BF of leg. There might be a linear relationship between BM/BF factor and the leg temperature.

6. Further Study
In this study, due to there are only few participate with small difference in their body parameters, the conclusion may not be convincing enough, so in the further study, following steps should be taken into consideration:

• Take more participates, whose body fat and body muscle ratios are significant different to each other in to the experiments
• Consider more temperature parameters, and focus on the leg and the BM/BF relationship to verify the equation between BM/BF of leg.
• As for the muscle will have large heat generation in the non-meditation state (muscle will generate much more heat at active state), so the future study should consider the active state thermal feeling and its relationship with the BM/BF rate.

References
[1] Alahmer, A., Abdelhamid, M., & Omar, M. (2012). Design for thermal sensation and comfort states in vehicles cabins. Applied Thermal Engineering, 36, 126-140.
[2] Huang, L., Ouyang, Q., & Zhu, Y. (2012). Perceptible airflow fluctuation frequency and human thermal response. Building and Environment, 54, 14-19.
[3] Luo, M., Zhou, X., Zhu, Y., & Sundell, J. (2016). Revisiting an overlooked parameter in thermal comfort studies, the metabolic rate. Energy and Buildings, 118, 152-159.
[4] Choi, J. H., Loftness, V., & Lee, D. W. (2012). Investigation of the possibility of the use of heart rate as a human factor for thermal sensation models. Building and Environment, 50, 165-175.
[5] Zhang, H., Huizenga, C., Arens, E., & Yu, T. (2001). Considering individual physiological differences in a human thermal model. Journal of thermal biology, 26(4-5), 401-408.
[6] Loftness, V., Choi, J. H., Hartkopf, V., Mattern, G., & Dubrawski, A. Bio-Sensing based Adaptive Thermal Comfort Controls.
[7] Nishimura, K. (1993). Dose the difference in percentage of body fat affect the skin temperature of extremities?. Jpn J Biometeor, 30, 187-196.
[8] Chudecka, M., Lubkowska, A., & Kępińska-Podhorodecka, A. (2014). Body surface temperature distribution in relation to body composition in obese women. Journal of Thermal Biology, 43, 1-6.
[9] Peterson, J. T., Repovich, W. E., & Parascand, C. R. (2011). Accuracy of consumer grade bioelectrical impedance analysis devices compared to air displacement plethysmography. International Journal of Exercise Science, 4(3), 2.