Analysis of thermal comfort with predicted mean vote (PMV) index using artificial neural network

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Abstract. The thermal comfort standard can be accessed with a predicted mean vote (PMV) index that has six variables: air temperature, air velocity, relative humidity, mean radiant temperature, clothing insulation, and metabolism rate. Calculation of the thermal comfort of a room issued with a PMV index is quite complicated, considering the determination of the effect parameters can take a long time because it has a non-linear relationship. The purpose of this study is to analyze the sensitivity parameters that affect thermal comfort and to develop an artificial neural network model to predict the thermal comfort of the PMV index with two different input scenarios. Sensitivity analysis of thermal comfort uses the rank Spearman method, whereas the modeling of artificial neural networks uses the backpropagation method using a total of 784 data as data training and testing. Based on the results of sensitivity analysis shows metabolism rate and clothing insulation have a significant effect on the sensitivity of thermal comfort. Prediction of thermal comfort with the PMV index using an artificial neural network is very effective and has higher accuracy. The results are proven by validating the two model scenarios with an R² value of 0.99 and low RMSE value.

1. Introduction
Thermal comfort is needed by the body so that humans can move well. Thermal comfort is defined as a condition or a person’s satisfaction with the thermal conditions of the environment [1]. In other words, it turns out that the heat felt by a person is not the temperature of the air but the temperature of the skin rather than responding to conditions in the surrounding environment. The thermal comfort standard is an index of the thermal sensation known as the predicted mean vote (PMV) index. PMV index is a function of six variables: physiological variables and the rest are environmental variables. The physiological or human personal variables are clothing insulation and activity level or metabolic rate. The environmental variables are air temperature, wind speed, relative humidity, and radiation temperature. Therefore, the thermal conditions felt by everyone in the same environment can have different sensations. PMV index values range from -3 to +3, which describes the feeling from cold to hot [2].

The calculation of PMV values issued by Fanger, 1982 [1] is very complicated when using manual calculations. Determination of effect variables can take a long computational time because it has a non-linear relationship and requires iterative in calculating non-linear equations. Hence, it is not practical to determine the value of PMV in real-time applications [3]. Therefore, we need computer modeling following the issues PMV model by Fanger, 1982 [1] for thermal comfort variables. The computational model that can be applied is an artificial neural network because it can be practically used to estimate non-linear relationships between input variables and output variables [4]. This research was to develop modeling artificial neural networks that are used to predict PMV index values that describe the conditions of thermal comfort in a room.
The purpose of the study is to analyze the parameters that affect thermal comfort, estimate the thermal comfort level using an artificial neural network as an alternative method with different input scenarios, and compare the results of the estimated thermal level using the artificial neural network model with the calculation model issued by Fanger, 1982 [1].

2. Research methodology
The study was conducted from May to July 2020. Modeling and analysis were carried out in the Department of Civil and Environmental Engineering, Faculty of Agricultural Technology, Bogor Agricultural University. The tools used in this study are calculators, laptop with Intel Core i3 processor specifications and equipped with Windows 10 64-bit operating system, visual basic application (VBA) in Microsoft Excel, Analyze-it in Microsoft Excel, and Microsoft Word. The materials used in this study are secondary data from research results [2,5-8]. Secondary data are variables that affect PMV index values.

2.1. Predicted mean vote
The determination of thermal comfort by a person can be determined by the predicted mean vote (PMV) index. PMV index using seven scales is used to measure thermal comfort level, as shown in Table 1.

Table 1. PMV index scales with thermal perception

| Scales | Thermal perception |
|--------|--------------------|
| 3      | Hot                |
| 2      | Warm               |
| 1      | Slightly warm      |
| 0      | Neutral            |
| -1     | Slightly cool      |
| -2     | Cool               |
| -3     | Cold               |

\[
PMV = 0.303e^{-0.036M} + 0.028x [(M - W) - 3.05 x10^{-3} \{5733 - 6.99(M - W) - Pa\} - 0.42 \{M - W\} - 58.15 - 1.7x10^{-5}M(5867 - Pa) - 0.0014M(34 - ta) - 3.96 x 10^{-8}fcl \{tcl + 272\}^4 - (tr + 273)^4\] - fcl hc (tcl - ta) \] (1)

Where \(M\) and \(W\) are the metabolic rates and external work, both in W/m²·s; \(Pa\) is the partial water vapor pressure in Pascal, and \(ta\) and \(tr\) are the air temperature and mean radiant temperature in degrees Celsius. The surface temperature of clothing, \(tcl\), and the convective heat transfer coefficient, \(hc\), can be calculated by Equation (2) and (3).

\[
tcl = 35.7 - 0.028 (M - W) - IcI [3.96x10^{-8}fcl x \{tcl + 273\}^4 - (tr + 273)^4 + fcl hc (tcl - ta)] \] (2)

\[
hc = \begin{cases} 
2.38(tcl - ta)^{\frac{1}{3}}, & \text{if } hc > 12.1\sqrt{Va} \\
12.1\sqrt{Va}, & \text{if } hc < 12.1\sqrt{Va}
\end{cases} \] (3)

\(Va\) is the air velocity in m/s and \(IcI\) is the clothing thermal resistance in m²·C/W. These two equations are solved iteratively until a prescribed degree of convergence is attained or the maximum number of iterations reached. While \(fcl\) is the ratio of body surface area covered by clothes to the naked surface area is defined by equation (4).
\[ f_{cl} = \begin{cases} 1.00 + 1.290I_{cl}, & I_{cl} \leq 0.078 \\ 1.05 + 0.645I_{cl}, & I_{cl} > 0.078 \end{cases} \] (4)

\( Pa \) is the water vapor pressure in Pascal, is easily relative to the relative humidity of the air, \( ha \) that can be calculated by equation (5)

\[ Pa = 10 \ ha \ e^{\left(\frac{(16.6536 - 4030.183)}{(T^{a} + 235)}\right)} \] (5)

2.2. Analysis of thermal comfort parameters

Analysis of the thermal comfort parameter was performed using a linear regression statistical method. Analysis of the relationship of the environmental parameter is carried out to study the strength and direction of the relationship between PMV index and environmental parameters by finding a coefficient of determination (R\(^2\)) and a linear regression equation using Microsoft Excel. The calculation of the coefficient of determination can be seen in equation (6). Linear regression explains the causal relationship variables using the equation model that can be seen in equation (7).

\[ R^2 = 1 - \frac{\sum_{i=1}^{N}(Y(i) - \bar{O}_t(i))^2}{\sum_{i=1}^{N}(Y(i) - \bar{Y})^2} \] (6)

\[ Y(i) \] is the value predicted by the model, \( \bar{O}_t(i) \) is the calculated value, \( \bar{Y} \) is the average of the calculated value, and \( N \) is the amount of data,

\[ Y = a + bx \] (7)

\( Y \) is a dependent variable which is the value of PMV index, \( X \) is an independent variable that reverses environmental parameters, \( a \) is a constant, and \( b \) is the slope coefficient of the regression line.

Meanwhile, the sensitivity analysis of thermal comfort was performed using the Spearman rank correlation statistical method using the Analyze-it program in Microsoft Excel. Spearman rank correlation values are between -1 to 1. The meaning of the Spearman rank value relationship can be seen in Table 2. The calculation of the Spearman coefficient can be calculated using equation (8) [9].

| \( rs \) (+/-) | Meaning  |
|---------------|--------|
| 0.01-0.19     | Very weak |
| 0.20-0.39     | Weak     |
| 0.40-0.59     | Moderate |
| 0.60-0.79     | Strong   |
| 0.80-1.00     | Very strong |

\[ r_s = 1 - \frac{6\Sigma(R(xi) - R(yi))^2}{n(n^2-1)} \] (8)

Where \( rs \) is the coefficient of Spearman. \( R(xi) \) is the ranking of data \( xi \), while \( R(yi) \) is the ranking of data \( yi \). After the coefficient of Spearman is obtained, parameters of thermal comfort are ranked. Based on the ranking, it can be seen the main parameters that influence the determination of thermal comfort with the PMV index.
2.3. ANN modeling for PMV index prediction

The artificial neural network model used three layers, that is the input layer, hidden layer, and output layer. The modeling is connected with a weight value that can capture patterns in the data. The weight value was identified in ANN modeling for the estimation of the PMV index, which states the level of thermal comfort. The ANN modeling used to get the weight value is the backpropagation algorithm method which has two phases: forward and backward propagation. This modeling is done by two different scenarios with different inputs. The chosen configuration for the first scenario model is 6-5-1 (six inputs, five hidden neurons in one hidden layer, and one output), which can be seen in Figure 1. Meanwhile, the chosen configuration for the second scenario model is 4-5-1 (four inputs, five hidden neurons in one hidden layer, and one output), which can be seen in Figure 2.

The performance of the model is assessed based on the value of the coefficient of determination ($R^2$) which can be calculated with equation (6) and the value of Root Mean Square Error (RMSE) which can be seen in equation (9). The value of $R^2 > 0.7$ states that a model is very good, whereas if the value of $R^2 < 0.4$ then the prediction model should not be used [12].

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (Y(i) - O(i))^2}$$

(11)

$Y(i)$ is the value predicted by the model, $O(i)$ is the calculated value which is the value of the PMV index issued by [1], and $N$ is the amount of data.

3. Results and Discussion

3.1. The relationship of environmental parameters with PMV index

Thermal comfort felt by a person is influenced by several environmental parameters, namely air temperature, mean radiant temperature, relative humidity, and air velocity. The relationship between these environmental parameters with thermal comfort can be seen based on the magnitude of the PMV index value with the change in each environmental parameter illustrated by a linear regression graph. Based on [13], a person will feel comfortable or neutral thermal conditions will be achieved if the PMV index value is 0, where the PPD value (percentage of respondents who are uncomfortable) reaches 5% or the percentage of respondents who is comfortable reaches 95%. Meanwhile, the range of comfortable
conditions is achieved if the PMV index value is between -0.5 and +0.5, where-in on this condition, the PPD value reaches 10% or the percentage of respondents who are comfortable reaches 90%. By knowing the relationship between each environmental parameter with the PMV index, it can also be seen the range needed by environmental parameters to achieve comfortable conditions.

3.1.1. Air temperature

The relationship of air temperature shows a positive relationship to thermal comfort that can be seen in Figure 3. Based on the linear regression equation, it can be announced that any increase in the PMV index by x can increase air temperature by 0.296x. In other words, the greater the air temperature, then the greater the PMV index value, or the sensation of someone feels will get hotter. Besides, it also obtained the coefficient of determination ($R^2$), i.e., 0.567. This $R^2$ value shows the air temperature affects the PMV index with a contribution of 56.7%.

$$y = 0.2896x - 7.0513$$

$R^2 = 0.567$

![Figure 3. Effect of changes in air temperature on the PMV index](image)

The results of the analysis corroborate the results of the study [14-16], which states that air temperatures and PMV index have a positive and linear relationship. Based on the linear regression equation, it can also be seen that air temperature is a comfortable or neutral condition (PMV=0), where it is estimated that approximately 95% of respondents feel comfortable reaching it when the air temperature is 24.3°C. While the comfortable air temperature range (PMV between -0.5 to +0.5), where it is estimated that around 90% of respondents feel comfortable being reached if the air temperature is 22.6-26.1°C.

3.1.2. Mean radiant temperature

The relationship of mean radiant temperature shows a positive to thermal comfort that can be seen in Figure 4. Based on the linear regression equation, it can be announced that any increase in the PMV index by x can increase mean radiant temperature by 0.231x. In other words, the greater the mean radiant temperature then, the greater the PMV index values, or the sensation of someone feels will get hotter. Besides, also obtained $R^2$ values are 0.567, which shows the mean radiant temperature affects the PMV index with a contribution of 56.7%.
Figure 4. Effect of changes in mean radiant temperature on the PMV index

The results of the analysis corroborate the results of the study [14-16], which states that mean radiant temperature and PMV index have a positive and linear relationship. Based on the linear regression equation, it can also be seen that comfortable or neutral conditions (PMV=0) reach it when the mean radiant temperature is 24.4°C. While the comfortable mean radiant temperature range (PMV between -0.5 to +0.5) is 22.3-26.5°C.

3.1.3. Relative humidity

The relationship of relative humidity shows a negative to thermal comfort that can be seen in Figure 5. Based on the linear regression equation, it can be announced that any increase in the PMV index by x can decrease relative humidity by 0.014x. In other words, the greater the relative humidity then, the smaller the PMV index values or the sensation of someone feels will get colder. Besides, it also obtained a minimal R² value is 0.052, which shows the relative humidity affects the PMV index with a small contribution of 5.2%. The small influence of relative humidity in increasing thermal comfort is evidenced in the graph that a single point of relative humidity can produce a variety of PMV index values. It can be said other factors are greater in increasing thermal comfort, along with changes in relative humidity.

Figure 5. Effect of changes in relative humidity on the PMV index
If the relative humidity relationship compared with air temperature and mean radiant temperature have an inverse relationship that indicates the greater the air temperature and mean radiant temperature, then the relative humidity value will be smaller. Based on this theory, it can be said that the results of the data show the corresponding results. Based on the results also obtained can be said, relative humidity has a small effect on thermal comfort compared with the four other environmental parameters. This reinforces the provision of [17], which states that there is no relative humidity limit set for thermal comfort.

3.1.4. Air velocity

The relationship of air velocity shows a negative to thermal comfort that can be seen in Figure 6. Based on the linear regression equation, it can be announced that any increase in the PMV index by x can decrease air velocity by 3.151x. In other words, the greater the air velocity, then the PMV index value will be smaller, or the sensation of someone feels colder. Besides, it also obtained a small R² value is 0.163, which shows the air velocity affects the PMV index with a small contribution of 16.3%.

![Figure 6. Effect of changes in air velocity on PMV index](image)

Based on the linear regression equation, it can also be seen that comfortable or neutral conditions (PMV=0) reach it when the air velocity is 0.2%. At the same time, the comfortable air velocity range (PMV between -0.5 to +0.5) is 0.08%-0.4%. Based on [17], states that increasing air velocity does not have a strong relationship that can increase thermal comfort, but is more effective in increasing heat loss when the mean radiant temperature is high, and air temperature is low. The increase in air velocity can be used to offset the increase in air temperature and mean radiant temperature of no more than 3°C. The magnitude of the effect of air velocity on thermal comfort is greatly influenced by individual factors such as clothing and activities undertaken by a person. Therefore, on the graph seen at one point, the wind speed can produce various PMV index values.

3.2. Sensitivity analysis of thermal comfort parameters

Sensitivity analysis is used to understand the behavior of environmental and human factors in measuring the PMV index. It is important to know which parameter has more influence on thermal comfort so that informed decisions are made on adjusting them, both at the design stage as well as during the operation lifetime of a building. Spearman coefficient calculation results compared with the coefficient of determination can be seen in Table 3.
Table 3. The results of the sensitivity analysis of thermal comfort parameters

| Parameter                | rs (+/-) | Meaning   | R²  |
|--------------------------|----------|-----------|-----|
| Mean radiant temperature | 0.813    | Very strong | 0.567 |
| Air temperature          | 0.795    | Strong    | 0.567 |
| Air velocity             | 0.476    | Moderate  | 0.164 |
| Clothing insulation      | 0.268    | Weak      | 0.101 |
| Relative humidity        | 0.164    | Very Weak | 0.052 |
| Metabolic rate           | 0.146    | Very Weak | 0.038 |

Based on the ranking and comparison between Spearman coefficient (rs) and coefficient of determination, it is found that thermal comfort is the most sensitive and strongly influenced by mean radiant temperature. At the same time, the parameter that has the least effect on thermal comfort is the metabolic rate. These results are not in line with the results of research from [14], which states the metabolic rate is the parameter that most strongly produces changes in the state of thermal comfort. The study by [14] explained that changes in the value of metabolic rate and clothing insulation could cause significant changes in the calculation of PMV index results that affect the sensitivity of thermal comfort. The clothing insulation is adjustable, so one may feel comfortable by putting on or removing layers of clothes. The metabolic rate is loosely related to a certain level of activity, and it is a bit difficult to adjust. Therefore, it is essential to condition the indoor environment to the expected level of activity of the building user.

Table 4. The results of sensitivity analysis of thermal comfort that only using data [7]

| Parameter                | rs (+/-) | Meaning   | R²  |
|--------------------------|----------|-----------|-----|
| Metabolic rate           | 0.808    | Very Strong | 0.709 |
| Clothing insulation      | 0.622    | Strong    | 0.291 |
| Air temperature          | 0.162    | Very weak | 0.005 |
| Air velocity             | 0.126    | Very weak | 0.010 |
| Relative humidity        | 0.083    | Very weak | 0.001 |
| Mean radiant temperature | 0.063    | Very weak | 0.002 |

Meanwhile, [18] confirmed that in the case at a light metabolic rate, PMV appeared very sensitive to mean radiant temperature and air velocity. This corroborates the results shown in Table 3 because the average metabolic rate values used in this study are 1.0 met, which is only focused on light activity indoors. The study by [14, 18] also states at a higher metabolic rate, the sensitivity of thermal comfort to metabolic rate becomes very strong, and other parameters become less significant. This is evidenced when the sensitivity is carried out again using only data [7] in Table 4 with the average metabolic rate is 2.5 met, indicating that the metabolic rate is the most sensitive parameter and the strongest relation to thermal comfort, while the four environmental parameters become less sensitive to thermal comfort. When the clothing insulation value is high (>0.9 clo), it can make this parameter less important in changing the person’s state of thermal comfort [14,18]. In Table 3, the maximum value of clothing insulation used is quite high at 1.5 clo, causing the results of this parameter to have a weak relationship to thermal comfort. Whereas when the average clothing insulation value used is 0.6 clo, as shown in Table 4, it shows that clothing insulation has a strong influence on thermal comfort. The results of these two sensitivity analysis show that although two human/or individual parameters have a very weak relationship, as in Table 3, in determining thermal comfort, the two individual parameters cannot be
ignored, which is proven given at a light and higher these parameters greatly affect the level of thermal comfort as evidenced in Table 4.

3.3. Thermal comfort prediction using ANN modeling

Artificial neural network (ANN) modeling is done in two different scenarios with different input data. The first scenario modeling is done by considering all the influencing the PMV index that describes thermal comfort. This modeling is done by 20,000 iterations. The learning process is carried out with five hidden layer values that produce 35 weights, which are constants that are representations of mathematical equations that explain the relationship between the six input parameters. The relationship between actual PMV index data and the results of the estimation of the ANN model for the first scenario is presented in Figure 7. The prediction of thermal comfort with the PMV index using the first scenario ANN model shows accurate results, as evidenced by a coefficient of determination of 0.99 and RMSE value of 0.14. This proves that the first scenario ANN model that considers all factors of thermal comfort influence can be used to predict the level of thermal comfort.

The results of the model validation are strengthened by the results of the comparison between the actual PMV index and the predicted PMV index that can be seen in Figure 8. In the figure, it also shows that there are some over and under-estimate samples, but in general, the trend of the line on the graph, which is the PMV from the model’s prediction, is close to the actual PMV index points. So it can be said to be an accurate model to be used to predict thermal comfort with the PMV index.

The second scenario ANN model is done to simplify the modeling by reducing individual parameter inputs, namely clothing insulation and metabolic rate, that the determination and calculation of these two variables are quite complicated. This model performed as much as 20,000 iterations as in the first scenario model. The learning process is carried out five hidden layer values so that it produces 25 weights. The relationship between actual PMV index data and the results of the estimation of the ANN model for the second scenario is presented in Figure 9. The prediction of thermal comfort using the second scenario ANN model shows inaccurate results with a coefficient of determination of 0.66 and an RMSE value of 0.73. This indicates that the second scenario modeling that eliminates who input data, which are individual parameters, has a large impact on modeling results considering these two factors significantly influence changes in the level of thermal comfort and described in the sensitivity analysis of the thermal comfort sub-section.

\[ y = 1.0057x \]
\[ R^2 = 0.99 \]

Figure 7. The relationship between the actual PMV index and the estimated results of the first scenario ANN model

Figure 8. Comparison of the actual PMV index and the first scenario ANN model

Figure 9. The relationship between the actual PMV index and the estimated results of the second scenario ANN model
Figure 9. The relationship between the actual PMV index and the estimated results of the second scenario ANN model

The second scenario model still does not provide sufficiently accurate results, so the modification of the second scenario ANN model is re-done so that it can improve learning skills in the learning process. This model was conducted using 161 training data, which only come from research [6]. The use of the data to PMV index measurement results is considered individual parameters constant. So that clothing insulation and metabolic rate for the second scenario model can be eliminated. The results of the relationship between the actual PMV index data and the estimation of the modification second scenario ANN model is presented in Figure 10. The prediction of thermal comfort using the modification second scenario ANN model shows accurate results with a coefficient of determination of 0.99 and RMSE value of 0.22. This proves that the modification second scenario ANN model that considers environmental parameters as input data can be used to predict thermal comfort represented by PMV index more easily, simply, and accurately than the second scenario model before and the first scenario model.

The results of the model validation are strengthened by the results of the comparison between the actual PMV index and the predicted PMV index that can be seen in Figure 11. The graph shows the line's general trend on the graph, which is the PMV index indicated by the modification second scenario model approaching the points of the actual PMV index. So the modification second scenario ANN model that only uses four environmental factors (air temperature, mean radiant temperature, air velocity, and relative humidity) as input data can be taken into consideration as illustrated by the PMV index while considering the two individual factors as the most sensitive factors to thermal comfort.
4. Conclusions

Based on the results of the research that has been done obtained several conclusions, namely:

1. The results of the sensitivity analysis show that metabolic rate and clothing insulation have a significant effect on thermal comfort. At a light metabolic rate, the PMV index appeared very sensitive to the mean radiant temperature. At a higher metabolic rate, thermal comfort sensitivity to metabolic rate becomes very strong, and other parameters become the less significant effect.

2. The prediction of thermal comfort using the ANN model can be used both the first scenario model that considers all thermal comfort parameters; and the second scenario model which is a simplification of the model by only using environmental parameters as the input model.

3. The estimates of thermal comfort using the ANN model with the calculation model issued by [1] show accurate results. The results are proven by validating the model scenarios with an $R^2$ value of 0.99 and a very small RMSE value.

Acknowledgments

Thank you to Sadewo Kusumo Digdoyo, Evandro Eduardo Broday, Predo M. Ferreira, Mahenda Kumar, and Lusi Susanti for their data in developing the current model.

References

[1] Fanger P O 1982 Thermal Comfort, Analysis and Applications in Environmental Engineering (Malabar: Robert E. Krieger Publishing Company).

[2] Kumar M and Kar I N 2009 Non-linear HVAC computations using least square support vector machines Energ Convers Manage 50 pp 1411- 8.

[3] Sahari K S M, Jalal M F A, Homod R Z, and Eng Y K 2013 Dynamic indoor thermal comfort model identification based on neural computing PMV index Earth and Environmental Science. (Selangor: IOP Publishing) pp 1-4.

[4] Aththajariyakul S and Leephakpreeda T 2005 Neural computing thermal comfort index for HVAC systems Energ Convers Manage 46 pp 2553-65.

[5] Digdoyo S K 2017 Evaluasi kenyamanan lingkungan fisik kerja pada ruang kuliah dan laboratorium di Fakultas Teknologi Pertanian Institut Pertanian Bogor (Bogor: Institut
Pertanian Bogor).

[6] Ferreira P M Silvia S M Ruano A E Negrier A T Conceiaco E Z E 2012. Neural network PMV estimation for model-based predictive control of HVAC IEEE World Congress on Computational Intelligence (Brisbane: WCCI) pp 1-8.

[7] Broday E E, Xavier A A P, and Oliveira R 2017 Comparative analysis of methods for determining the clothing surface temperature (tcl) in order to provide a balance between man and the environmental Int. J. Ind. Ergon. 57 pp 80-7.

[8] Susanti L and Aulia N 2013 Evaluasi kenyamanan termal ruang sekolah SMA Negeri di Kota Padang Jurnal Optimasi Sistem Industri 12 1 pp 310-6.

[9] Puspitaningdyah R A 2012 Analisis korelasi statistika antara populasi jumlah penduduk dan pengguna internet negara-negara di dunia Jurnal Ekonomi 318 pp 41-8.

[10] Azmi K 2017 Analisis sensitivitas emisi gas metana (CH₄) pada sawah dengan metode korelasi rank Spearman (Bogor: Institut Pertanian Bogor).

[11] Arif C, Setiawan B I, Widodo S, Rudiyanto, Hasanah N A I, and Mizoguchi M 2015 Pengembangan model jaringan syaraf tiruan untuk menduga emisi gas rumah kaca dari lahan sawah dengan berbagai rezim air Jurnal Irigasi 10 pp 1-10.

[12] Olori VE, Brotherstone S, Hill WG, McGuirk BJ. 1999 Fit of standard models of the lactation curve to weekly records of milk production of cows in a single herd Livest. Prod. Sci. 58 1 pp 55-63.

[13] Karyono T H 2001 Penelitian kenyamanan termis di Jakarta sebagai acuan suhu nyaman manusia Indonesia Dimensi Teknik Arsitektur 29 pp 24-33.

[14] Moutela R Carrilhon J D Silva M G 2015 Sensitivity of the PMV index to the thermal comfort parameters Sustainable Cities: Designing for People and the Planet (Coimbra: Energy for Sustainability) pp 1-4.

[15] Samsudin S Durrani F Eftekhari M Uno Y 2016 Temperature sensitivity analysis of thermal comfort in a UK Residential Building The Fifth International Conference on Human-Environment System (Nagoya: ICHES) pp 1-10.

[16] Sugiono 2016 Innovation of building design based on predicted mean vote (PMV) index for increasing human comfort Journal of Architecture and Built Environment 43 pp 1-8.

[17] [ASHRAE] American Society of Heating, Refrigerating, and Air Conditioning Engineers 2004. Thermal Environment Conditions for Human Occupancy Standard 55 (Atlanta: ANSI).

[18] Alfonso F R A Palella B I Riccio G 2011 The role of measurement accuracy on the thermal environment assessment by means of PMV index Build Environ 46 pp 1361-9.