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Development of Equation for Predicting of Outdoor Thermal Comfort for Individuals During Nighttime in Tropical Humid Climate

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ABSTRAK

Faktor panas matahari menjadi penyebab utama rasa tidak nyaman saat beraktivitas di luar ruangan dan hal ini tidak terjadi pada malam hari. Namun perlu dipastikan juga apakah manusia merasa nyaman di malam hari, meski tidak ada sinar matahari. Studi ini bertujuan mengembangkan persamaan regresi untuk menprediksi skala kenyamanan manusia yang beraktifitas di ruang luar saat malam hari didaerah beriklim tropis lembab. Dalam studi ini diterapkan metode penelitian lapangan yang melibatkan 80 responden orang dewasa terdiri atas 40 laki laki dan 40 perempuan dengan lokasi di ruang luar di iklim tropis lembab. Metode pengumpulan data menggunakan kuesioner. Kepada para responden sebagai subyek ditanyakan respon tingkat kenyamanan pada saat mendapat penetrasi iklim setempat yang menyentuh tubuhnya. Saat bersamaan dilakukan pengukuran variabel iklim sekitar subyek. Iklim yang diukur terdiri atas suhu udara, suhu radiasi, kelembapan relatif, dan kecepatan udara. Teknik analisis data yaitu deskriptif kuantitatif. Hasil penelitian yaitu ditemukan 2 persamaan regresi yaitu untuk kasus orang duduk dan berjalan santai. Persamaan regresi tersebut selanjutnya divalidasi dengan melakukan perbandingan terhadap persamaan lainnya yaitu PMV dan PET. Persamaan regresi yang dihasilkan dari studi ini bermanfaat untuk pengambilan keputusan tentang fasilitas dan desain ruang luar yang memberi rasa nyaman bagi manusia saat malam hari.

ABSTRACT

The sun's heat factor is the leading cause of discomfort when doing outdoor activities, which does not happen at night. However, it is also necessary to ensure that humans feel comfortable at night, even without sunlight. This study aims to develop a regression equation to predict the comfort scale of humans doing outdoor activities at night in humid tropical climates. This study applied a field research method involving 80 adult respondents consisting of 40 men and 40 women in an outdoor location in a humid tropical climate. The data collection method uses a questionnaire. Respondents as subjects were asked about their comfort level when they received local climate penetration that touched their bodies. At the same time, climate variables around the issue were measured. The climate measured consists of air temperature, radiation temperature, relative humidity, and air speed. The data analysis technique is quantitative descriptive. The research results found 2 regression equations, namely for the case of people sitting and walking casually. The regression equation was then validated by comparing with other equations, PMV and PET. The regression equation found by this study helps make decisions about outdoor space design that provide a sense of comfort for humans during nigthtime

1. INTRODUCTION

Community activities in outdoor areas, in humid tropical cities, can take place day and night. At night, when there is no heat from solar radiation, people are free to do outdoor activities, both for work and recreation. The sun's heat factor, which is the main cause of discomfort during outdoor activities, does not occur at night. However, it is also necessary to ascertain whether humans feel comfortable at night, even though there is no sun. It could be possible because in a certain time, the air temperature may be too high at night, and that can still cause feel of thermally uncomfortable (Lopes et al., 2022; Zeng et al., 2020). Likewise, discomfort may occur if the air temperature is too low, or the wind blows too fast, therefore it is suspected of causing a feeling of cold (Baruti et al., 2023; Saputra & Lukito, 2017).

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If humans feel uncomfortable with the surrounding climate, then logically it can cause a decrease in work productivity. This question needs to be answered by conducting a study of the variables that affect the thermal comfort of humans who do activity at night in oudoor space. Some of studies on the relationship between thermal comfort variables in humid tropical climates during the day have been carried out by researchers (Aghamolaei et al., 2022; Johansson et al., 2004; Karyono et al., 2020). In the world, the number of study on outdoor comfort still only about 30% compared to the study of indoor comfort. Among them, there were not many the study in the tropical humid area (Li et al., 2021; S. R. Sangkertadi et al., 2022). However it is very limited the research on outdoor comfort with a special case of night situation. Therefore the novelty of this study is about a study of outdoor comfort at night situation in tropical humid area.

Air temperature can be considered as a single variable in the perception of thermal comfort for certain conditions. Wind and air temperature are referred to as the main variable pair in the outdoor thermal comfort response, also coupled with the air humidity (S. Sangkertadi & Syafriny, 2016; Santi et al., 2019). However, during the day, the influence of the sun's heat causes a change in radiation temperature coupled with wind speed (Johansson et al., 2014; Shang et al., 2019). Apart from meteorological influences from the atmosphere, microclimatic factors can also be influenced by the nature of landscape materials which can cause microclimate changes. Furthermore, the urban landscape also influences the impact of thermal comfort in outdoor spaces, both during the day and at night (Johansson & Yahia, 2012; Yang et al., 2018). Human body, cloth, and activity are human variables that affect sense of thermal comfort (Callejas et al., 2020; Hildegardis et al., 2019).

Many of regression equations on the perception of outdoor comfort in humid tropical climates have been produced but are limited for using in day-time due to the field observation that have been conducted in day-time (Huang & Peng, 2019; S. Sangkertadi & Syafriny, 2014, 2016). Whereas at night, research on the response and variables of outdoor thermal comfort has not been much discussed, it was noted, among others (Gupta et al., 2015; Meili et al., 2021). The PET, Psychologically Effective Temperature in the Rayman Model is one of the index of thermal comfort that be used widely for study on outdoor comfort by many researchers (Diani, 2015; Matzarakis et al., 2010). PET is a measure of temperature that shows the response of the human body to the level of comfort. PET is based on typical indoor conditions, where the PET value in a comfortable response position is a measure of temperature where the wind is weak, there is no solar radiation, but it found thermal equilibrium in the human body, which can occur in a complex outdoor spaces. However some of authors have found that there were deviation between the PET calculation and from questionnaire (Ballinas et al., 2022; Iskandar et al., 2021). Another comfort index that commonly used in the study of comfort is PMV. The ISO 7730-2005 mention that the PMV is limited to be used for case of human in a moderate thermal environment in indoor. A study of previous study show that there is a deviation when apply PMV in the case of outdoor comfort (Fang et al., 2017).

This study is provide information about the study of outdoor thermal comfort with special case for night-time activity in the geographical area of humid tropical climates. This study was conducted on the relationship between variables that determine the perception of comfort at night-time. The aim is to produce regression equations that can be used to predict the level of outdoor thermal comfort in humid tropical climate at night time. Regression equations are generally limited to a certain range according to the specified variables. However, the validity of the use of the regression equation to predict the level of thermal comfort has been tested, therefore it is feasible to continue to develop for various scopes or certain other variable ranges. The regression equations which are generated by this study can be used to predict whether people feel comfortable or not while doing outdoor activities at night, both in state of sitting while doing light work or in walking leisurely. By using the equation, we can state the prediction of comfort level, and can do anticipation to avoid an uncomfortable situation. When the prediction is found in the range of classification uncomfortable, then it can anticipate by various actions, for example by preparing clothes that are tighter if it is suspected that people will feel cold. Conversely, if it is suspected that we will feel hot, then the environment around the workplace can be equipped with a mechanical ventilation device such as a fan to provide a breath of fresh air that can help to evaporate the sweat.

2. METHOD

This study employed field measurements and questionnaires to construct regression equations comprising specific measurable variables. These variables encompass two categories: climate variables and human variables. The climate variables group comprises air temperature, globe temperature, wind speed, and air humidity. Globe temperature signifies the average radiant temperature. The human variables encompass height, weight, type of activity, and clothing. Data regarding the respondents' height and weight are necessary to ascertain the size of the skin area or the du Bois area (Lucchese et al., 2016). The consideration of the body's skin surface area is crucial due to the penetration of radiant heat from the surroundings and the convective thermal energy generated by wind pressure against the human skin. Consequently, a heat exchange occurs between the skin and the local climate.

In this study, the activities of the respondents were limited to a seated position with light work and leisurely walking on a treadmill. Respondents were instructed to wear a tropical dress style (approximately 0.5 – 0.6 clo). “Clo” represents the unit of clothing type. The study comprised 40 adult male and 40 adult female respondents. Each respondent engaged in outdoor activities, either sitting or walking on a flat treadmill, simulating normal road walking by adjusting the treadmill's velocity. In this setup, respondents experienced varying microclimate conditions at night within an entirely open outdoor space. Climate variables such as air temperature, humidity, and globe temperature naturally fluctuated. Wind speed adjustments were made using a standing fan placed near the subjects, and an anemometer was employed to measure wind speed close to the subjects' necks. Respondents experienced different wind speeds naturally and/or through the addition of air velocity from the standing fan, categorized into three wind speed range groups: 0.1 to 1 m/s, 1 to 2 m/s, and 2 to 4.5 m/s. Concurrently, measurements were taken for air temperature, globe temperature, and air humidity around the human body. The measurement equipment included a thermo-hygrometer, anemometer, and globe thermometer with a data logger. Respondents' weight and height information was collected.

Each respondent experienced varying climate conditions for 5 minutes and promptly completed a comfort perception questionnaire consisting of a 7-point scale (3=hot; 2=warm; 1=slightly warm; 0=comfortable; -1=slightly cool; -2=cool; -3=cold), as detailed in Table 1. The 7-point comfort scale is widely utilized by researchers studying thermal comfort (Schweiker et al., 2016). Following each exercise, respondents were given a 10-minute rest before engaging in another exercise with a different climate exposure. Each respondent participated in three exercise sessions. The comfort scale is show in Table 1.

Table 1. The Comfort Scale

Scale	Perception
-3	Cold
-2	Cool
-1	Slightly Cool
0	Comfortable/ Neutral
1	Slightly Warm
2	Warm
3	Hot

In total, 240 responses were collected from the respondents, encompassing both sitting and walking positions. The regression equation for the sitting activity is represented as Ym_d = f(Xi), where Ym_d signifies the output indicating the level of outdoor thermal comfort at night while sitting. Xi represents the combination of microclimate and human variables. Meanwhile, for relaxed walking activity, the regression equation is denoted as Ym_j = f(Xi), where Ym_j stands for the output indicating the level of outdoor thermal comfort.

3. RESULT AND DISCUSSION

Result

During the measurement process, for case of people in sitting state. The result variation of air temperature, air humidity, air speed, and distribution of responses are describe on the result. For the first variation of air temperature applied to the respondents in sitting state is show in Figure 1.

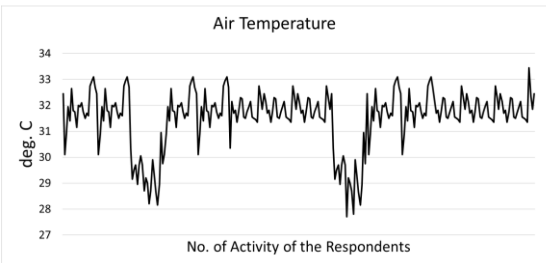

Figure 1. Variation of Air Temperature Applied to the Respondents in Sitting State

Base on Figure 1, during the measurement process, for case of people in sitting state, the maximum air temperature was noted 33.45 ^{0}C and minimum was 27.7^{0}C, the average was 31.52 ^{0}C, the maximum-minimum deviation was 5.75^{0}C, or 18%. It is noted that the air temperature at night from 18.00 to 21.00 is quite warm, because it is still affected by the hot air and solar radiation during the morning and afternoon, and due to the impact of heat production of settlements and the traffic activities which are still active during these hours. Then Variation of air humidity applied to the respondents in sitting state is show in Figure 2.

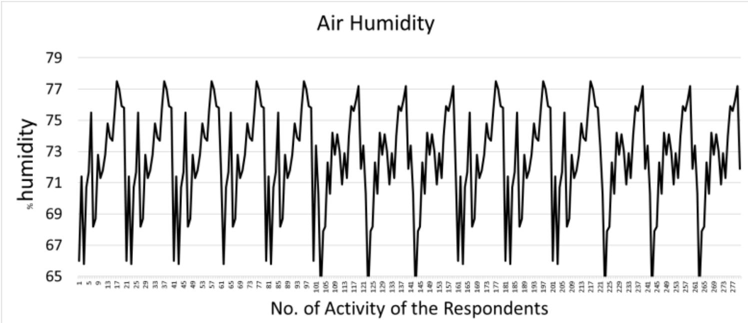

Figure 2. Variation of Air Humidity Applied to the Respondents in Sitting State

Base on Figure 2, the maximum of air humidity was measured on 77.5% and minimum was 63.9%, the average is 72.45%, with a maximum deviation 13.6%, or 18% of the average. It is normal because at night, usually in the tropical humid area, the air moisture is higher then during day time. Variation of air speed applied to the respondents in sitting state is show in Figure 3.

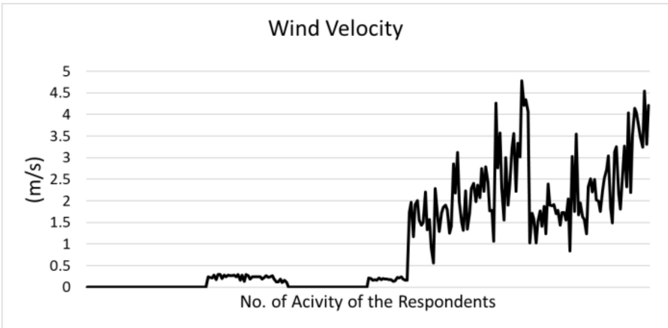

Figure 3. Variation of Air Speed Applied to the Respondents in Sitting State

Base on Figure 3, show the maximum difference in body skin area (A du_Bois) of the respondents was about 0.44 m^2, where the maximum of skin area was 2.03 m^2, the minimum was 1.6 m^2, and the average was 1.82 m^2. The globe temperature during measurement did not change significantly, where the maximum was 29^{0}C, minimum was 25.6^{0}C, and the average was 26.69^{0}C, with a maximum deviation of 3.4^{0}C. The indication of comfort perceptions that felt by respondents includes feel of hot, slightly warm, comfortable, slightly cool, and cold. Each perception was given a score of 2 for feeling hot, 1 for feeling slightly warm, 0 for comfortable, -1 for feeling slightly cool and -2 for perception of cool. Distribution of responses of the respondents in sting is show in Figure 4.

Figure 4. Distribution of Responses of the Respondents in Sitting

Analysis of the relationship between the value of perception by questionnaire and the microclimate measurement were carried out by using MS Excel in order to build the regression equations. The correlation coefficients among the variables were then obtained as show in Table 2.

Table 2. Correlation Factor Between Variables for Case People in Sitting Activity

	Ta	HR	v	Adu	Tg	Ym_d
Ta	1					
HR	0.13	1				
v	0.09	0.09	1			
Adu	-0.03	-0.37	-0.03	1		
Tg	0.11	-0.02	0.16	0.19	1	
Ym_d	0.29	0.18	-0.65	0.01	-0.06	1

Base on Table 2 it was found that the globe temperature has a very small effect, namely -0.06 on perceptual responses, therefore in the regression equation the globe temperature variable is omitted or neglected. Likewise, the body skin area (Area of du_Bois) in this case did not show a significant correlation, only 0.01 to the response of thermal comfort perception (Table 2). Wind speed reach the greatest correlation value, namely -0.65. Therefore, the variables which have moderate and good values of correlation coefficients are air temperature, air humidity and wind speed. The result of the regression equation for people in sitting state with a light activity is as follows:

$$Y_{m\_d} = -8{,}54 + 0.22ta + 0.03RH - 0.56\,v \quad (r = 0.7) \qquad \text{(Eq 1)}$$

Where t_a is air temperature (in ^{0}C), RH is air humidity (in %), and v is wind speed (in m/s). The equation is limited for adult which is wearing tropical clothing. The range of perceptions (*Ym_d*) of comfort includes feelings of cold, slightly cold, comfortable, slightly warm, warm and hot as shown in the Table.1. This equation has moderate precision with r value 0.7. The second case is for those of the respondents who are in walking activity. The climate environment surrounds the body of the respondents were almost the same as the situation for case of the people in sitting state. It was noted that the fluctuation of air temperatures were from 28.6^{0}C to 33.3^{0}C. Air humidities were from 64.2% to 76.7%. Air velocities were from 0.36 m/s to 3.46 m/s. The result of measurement of the local climate is show in Figure 5, Figure 6, Figure 7, and Figure 8.

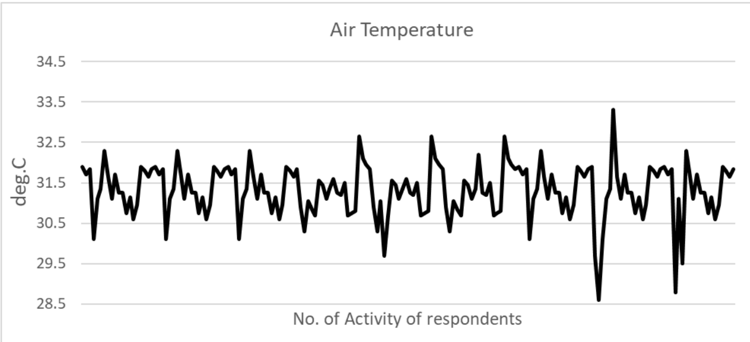

Figure 5. Variation of Air Temperature Surround the Respondents in Walking Activity

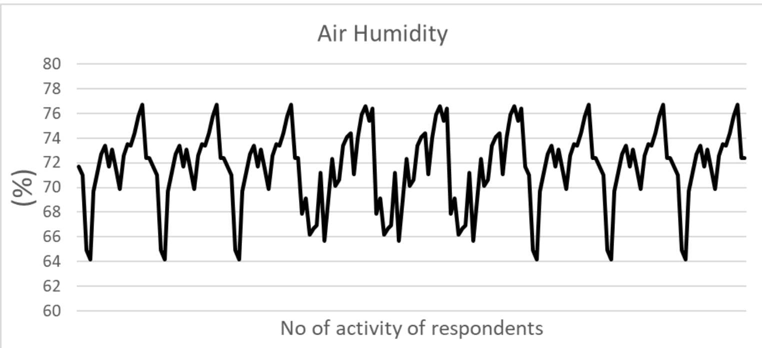

Figure 6. Variation of Air Humidity Surround the Respondents in Walking Activity

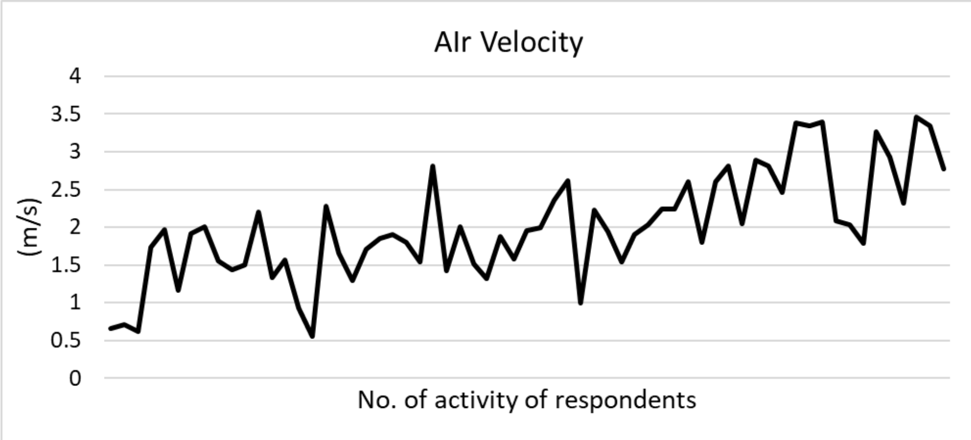

Figure 7. Variation of Air Velocity Surround the Respondents in Walking Activity

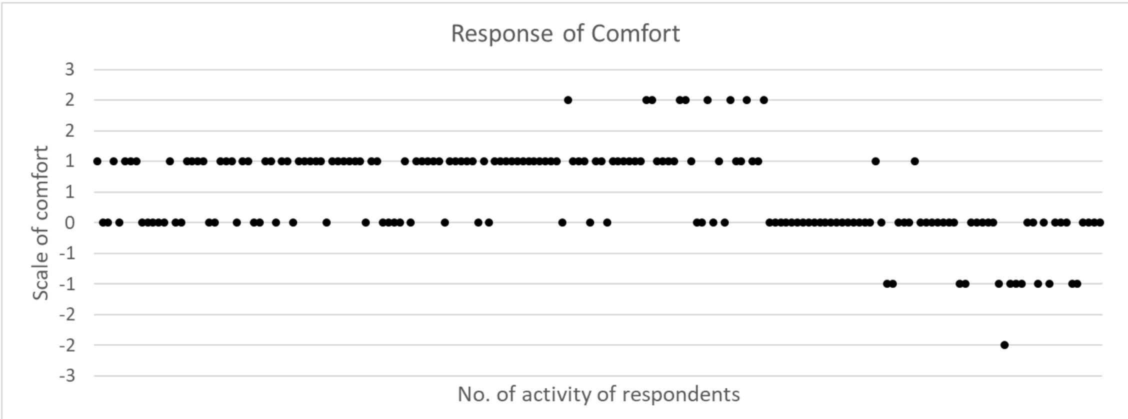

Figure 8. Distribution of Responses of the Respondents in Walking Activity

In the process to determine the most influenced variables on comfort it was found that there is a different from the case of the people in sitting state, where in the case of walking, the influence of the *Adu* (skin area) is enough significance with the value of correlation coefficient is -0.24 as show in Table 3.

Table 3. Correlation Factor Between Variables for Case People in Walking Activity

	Ta	HR	v	Adu	Tg	Y_mj
Ta	1.00					
HR	0.43	1.00				
v	0.04	0.04	1.00			
Adu	-0.03	-0.17	0.19	1.00		
Tg	0.51	0.12	0.27	0.03	1.00	
Y_mj	0.23	0.18	-0.68	-0.24	-0.11	1.00

As show in Table 3 the role of air movement to influence the sense of thermal comfort for walking people is also high significance, where it is found the correlation coefficient is -0.68. While the influence of air temperature is moderate, with value of correlation coefficient 0.23. Likewise, the relative humidity is not too high to make impact on comfort with the value of correlation coefficient only 0.18.

$$Y_{m\_j} = -\ 2.98 + 0.15ta + 0.007RH - 0.63v - 0.51Adu \qquad (r=0.7) \qquad \text{(Eq.2)}$$

Where t_a is air temperature (in ^{0}C), RH is air humidity (in %), and v is wind speed (in m/s), and Adu is the skin area of human body (in m^2). The equation is limited for adult and wearing tropical clothing. The range of perceptions (Y_{m_j}) of comfort includes feelings of cold, slightly cold, comfortable, slightly warm, warm and hot. This equation has moderate precision with r value 0.7. Difference between questionare and caculations for case of people in walking activity is show in Table 4 and Table 5.

Table 4. Difference Between Questionare and Caculations for Case of People in Walking Activity

Feel	Number of perceptions by questionnaire (vote)	Number of Perceptions by PET Calculation	Number of Perceptions by PMV Calculation	Number of Perceptions by New Regression Equation	Differences between Questionnaire and PMV	Differences between Questionnaire and PET	Differences between Questionnaire and Regression Equation
Hot	0	0	0	0	0	0	0
Warm	10	98	233	0	233	88	10
Slightly Warm	79	142	7	113	106	63	34
Comfortable	126	0	0	107	107	126	19
Slightly Cool	23	0	0	20	20	23	3
Cool	2	0	0	0	0	2	2
Total votes	**240**	**240**	**240**	**240**			
Average of Differences (votes)					**93**	**60**	**14**
Average of Differences (in %)					**39%**	**25%**	**6%**

Table 5. Difference Between Questionare and Caculations for Case of People in Sitting

Feel	Number of perceptions by questionnaire (vote)	Number of Perceptions by PET Calculation	Number of Perceptions by PMV Calculation	Number of Perceptions by New Regression Equation	Differences between Questionnaire and PMV	Differences between Questionnaire and PET	Differences between Questionnaire and Regression Equation
Hot	0	0	0	0	0	0	0
Warm	8	156	192	0	192	148	8
Slightly Warm	50	84	47	42	5	34	8
Comfortable	119	0	1	149	148	119	30
Slightly Cool	57	0	0	47	47	57	10
Cool	6	0	0	2	2	6	4
Total votes	**240**	**240**	**240**	**240**			
Average of Differences (votes)					**79**	**73**	**12**
Average of Differences (in %)					**33%**	**30%**	**5%**

Base on Table 4 and Table 5, the simulations were made with different wind speed values from 0.5 to 1.5 m/s. The results show that for the case of people in walking activities, the increase of wind speed can influence the perception change of comfort from a slightly warm to feel comfortable. Perception of comfort by using the equation is show in Table 6.

Table 6. Perception of Comfort by Using the Equation

Hour	Micro Climate			Adu	Sitting		Walking	
	Ta	RH	v		Ym_d	Perception	Ym_j	Perception
18	33.1	63.9	0.77	2	0.2	Comfortable	0.9	Slightly Warm
19	31.7	70.1	1.9	2	-0.5	Comfortable	0.0	Comfortable
20	29.4	72.8	2.2	2	-1.1	Slightly Cool	-0.5	Slightly Cool
21	28.1	76.2	2.6	2	-1.5	Cool	-0.9	Slightly Cool
22	27.7	77.5	2.7	2	-1.6	Cool	-1.0	Slightly Cool

Base on Table 6, while in the case of the subject who are in sitting and working lightly, it is predicted that by the same values of wind speed (from 0.5 to 1.5 m/s) the people still feel comfortable (Figure 9) (Table 7). Effect of wind speed in change of comfort perception is show in Table 7 and Figure 9.

Table 7. Effect of Wind Speed in Change of Comfort Perception

Ta	RH	v	Adu	Walking Leisurely		Sitting with Light Activity	
(⁰C)	(%)	(m/s)	m²	Scale	Perception	Scale	Perception
33.1	63.9	0.5	2	1.10	Slightly warm	0.4	Comfortable
33.1	63.9	0.6	2	1.03	Slightly warm	0.3	Comfortable
33.1	63.9	0.7	2	0.97	Slightly warm	0.3	Comfortable
33.1	63.9	0.8	2	0.91	Slightly warm	0.2	Comfortable
33.1	63.9	0.9	2	0.85	Slightly warm	0.2	Comfortable
33.1	63.9	1	2	0.78	Slightly warm	0.1	Comfortable
33.1	63.9	1.1	2	0.72	Slightly warm	0.0	Comfortable
33.1	63.9	1.2	2	0.66	Slightly warm	0.0	Comfortable
33.1	63.9	1.3	2	0.59	Slightly warm	-0.1	Comfortable
33.1	63.9	1.4	2	0.53	Slightly warm	-0.1	Comfortable
33.1	63.9	1.5	2	0.47	Comfortable	-0.2	Comfortable

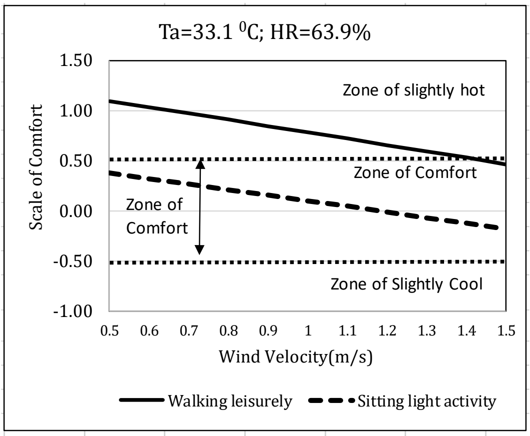

Figure 9. Influence of Wind Speed to Increase Comfort Perception

Base on Table 7 and Figure 9, the decrease in the perception of thermal comfort due to change of climate variables is shown as a linear form, as is the regression equations which also show a model of linear equations. In the case of people in walking activities, the feeling of comfort begins when the wind increases and reaches 1.5 m/s (Figure 9) (Table 7). Those lead us to state that the wind speed has also a significantly sensitivity in affecting the thermal comfort of people who are doing an activity at outdoor spaces in humid tropical climates at night time. Effect of air temperature in change of comfort perception is show in Table 8.

Table 8. Effect of Air Temperature in Change of Comfort Perception

Ta	RH	v	Adu	Walking Leisurely		Sitting with light activity	
(⁰C)	(%)	(m/s)	m²	Scale	Perception	Scale	Perception
25.5	65	1	2	-0.35	Comfortable	-1.5	Cool
26	65	1	2	-0.28	Comfortable	-1.4	Slightly cool
26.5	65	1	2	-0.20	Comfortable	-1.3	Slightly cool
27	65	1	2	-0.13	Comfortable	-1.2	Slightly cool
27.5	65	1	2	-0.05	Comfortable	-1.1	Slightly cool
28	65	1	2	0.03	Comfortable	-1.0	Slightly cool
28.5	65	1	2	0.10	Comfortable	-0.9	Slightly cool
29	65	1	2	0.18	Comfortable	-0.8	Slightly cool
29.5	65	1	2	0.25	Comfortable	-0.7	Slightly cool
30	65	1	2	0.33	Comfortable	-0.6	Slightly cool
30.5	65	1	2	0.40	Comfortable	-0.4	Comfort
31	65	1	2	0.48	Comfortable	-0.3	Comfort
31.5	65	1	2	0.55	Slightly hot	-0.2	Comfort
32	65	1	2	0.63	Slightly hot	-0.1	Comfort
32.5	65	1	2	0.70	Slightly hot	0.0	Comfort
33	65	1	2	0.78	Slightly hot	0.1	Comfort

Base on Table 8 show simulation that carried out to determine the effect of air temperature change with applying a constant wind speed of 1 m/s and a constant air humidity of 65%. The results show that higher air temperature increases discomfort, or feel hotter. Or vice versa if the air temperature will be lower then it will also increase the feeling of discomfort because people feel cool or slightly cool, the display is show in Figure 10.

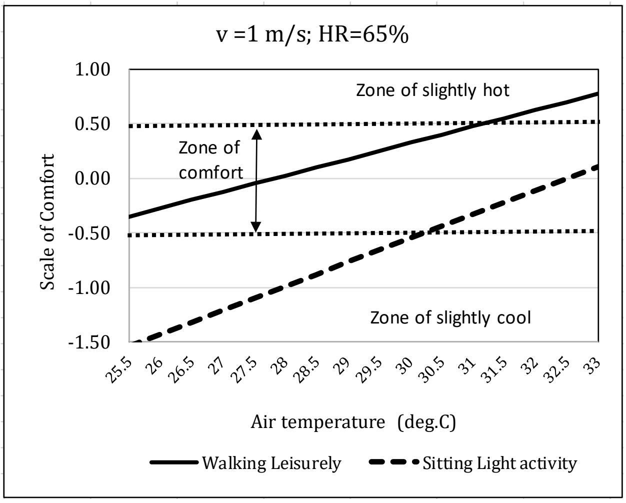

Figure 10. Influence of Change of Air Temperature on Comfort Perception

Figure 10 shows that in the case of the subject in sitting and working lightly, they will feel a bit cold with a temperature less than 30 ^{0}C, a wind speed of 1 m/s and relative air humidity of 65%. Whereas for the subject in walking activity, in the same climate situation, people feel comfortable. This can happen due to the influence of the body's metabolic factors. People in sitting and relaxing produce lower thermal metabolism rate than in walking activity. The body's thermal response to the environmental climate will also different following the body's thermal metabolism. When people sit relaxed and get excess wind flow, they will feel cooler. While if they walk, they need more pression of wind to cool the body and therefore feel comfortable. Therefore the rationale or logical explanation of the two regression equations can be accepted.

Discussion

The discussion encompasses simulations utilizing the regression equation and a comparison with the PMV model (Fang et al., 2017) and the PET model (Matzarakis et al., 2010). The Rayman program was employed to compute PMV and PET values. Based on the measured data, the comfort scale can be calculated using the PMV and PET models. A comparison between the questionnaire results, PMV, PET, and Ym_j (output from the regression equation) for individuals engaged in walking activities. The findings suggest that the Ym_j values exhibit the smallest discrepancy from the questionnaire results. The difference in votes-perceptions between the questionnaire and the regression equation (Ym_d) averages only 14 votes, corresponding to a 6% deviation.

In contrast, the utilization of the PMV and PET models results in discrepancies of 93 and 60 votes, respectively, out of the 240 votes. This translates to PMV and PET deviations of 25% to 39%. From the questionnaire results, it was found that 126 individuals felt comfortable, whereas through calculations using the regression equation, 107 individuals were reported to be comfortable. However, when utilizing the PMV and PET methods, no one reported feeling comfortable (E. & Kusumawanto, 2019; Wilis et al., 2020). Therefore, based on this comparison, it is evident that the regression equation provides more accurate results compared to PET and PMV for this case. Furthermore, based on the utilization of the PMV and PET formulas, more individuals reported feeling warm (98 and 233 people). In contrast, according to both the questionnaire results and the application of the regression equation, only a few individuals felt warm (0 and 10 people) (Ngo et al., 2022; Nomoto et al., 2021).

Further comparisons were conducted for cases involving individuals engaged in sitting activities, as demonstrated. Notably, the outcomes derived from the questionnaire and the regression equation differ significantly from the results obtained via PMV and PET calculations. For scenarios involving individuals with sedentary activities, the PMV and PET calculations exhibit a deviation of approximately 30% when compared to the questionnaire results. Similar results were shown by previous study that found in Singapore, that outdoor areas at 18.00 where the air temperature is still warm around 31 to 33^{0}C, while at 21.00 it has decreased to around 29^{0}C to 31^{0}C (Yang et al., 2018).

By using the regression equation, some simulations can be made to find out how the effect of changes in wind speed and temperature on increasing thermal comfort in outdoor space during nighttime. The application of the equations can be carried out in architectural design practice and for determination of utility equipment for outdoor facilities that are actively used at night, such as in cafes, recreational spaces, and parks. At certain times, outdoors at night, it may be necessary to have a standing fan equipment to increase the wind speed in order to serve people feel more comfortable. As a suggestion for further studies is the development of outdoor thermal comfort models for people who carry out more diverse activities and wear more varied types of clothing in humid tropical climate at night time.

4. CONCLUSION

In general, it can be concluded that people feel changes in comfort when they are penetrated by different environmental climates. At night, the factors of air temperature, air humidity, wind speed, and skin area of the body can be expressed as determining factors for changes in the feeling of thermal comfort for adults who are in a state of doing activities in humid tropical climates. Through this study, two regression equations were derived to predict whether individuals feel comfortable when exposed to specific climatic conditions outdoors at night. These equations are specifically tailored for adults wearing tropical clothing, with two equations provided for individuals engaged in moderate sitting activities and those walking slowly.

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