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Human Comfort Period Outside and Inside Bamboo Stands

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ABSTRACT
Four models (sine, exponential-sine, power-sine and logarithmic-sine) were conducted to fit the daily cycle of sunlight intensity inside and outside bamboo stands. Exponential-sine curve was the best among others. Since the shadowing effect inside bamboo stands, the glare is dodged and human visual comfort period increases 4.5 h longer. Sunrays radiation effect toward temperature and RH follow the sine function, while earth's surface energy follow exponential-sine equation for open space and sine equation for inside bamboo stands. Best equations for fitting the daily cycle of temperature and RH based on sunrays radiation and earth's surface energy effects have high coeficient of determination. According to those equations, the thermal comfort temperature period is 13 h long in open space while it is 16.5 h long inside bamboo stand. RH in both locations is high. Air inside bamboo stand is wetter. Human is much more tolerate against RH than temperature, thus temperature is dominant affecting human comfort. The hourly measurements of discomfort index prove during working hour, labor could comfortly work 1.5 h longer inside bamboo stand than in open space. Heat index measurements also show that labor would be safe from heat injury 5 h longer inside bamboo stands.

Key words: Bamboo stands, climate, heat index, human comfort, sunlight intensity

INTRODUCTION
Each people around the globe is always affected by weather and climate everytime. Weather and climate elements such as sunlight intensity, temperature and Relative Humidity (RH) are playing an important role to the human life. For gaining healthy, powered and comfortable life, people should adapted to every changes in those weather and climate elements. Human choices for his type of food, clothing and residential are commonly highly correlated with his surrounding sunlight intensity, temperature and Relative Humidity (RH). Weather and climate are affected to the human physical health and psycological condition (e.g., mental and emotion). Each people reacts to the changes on weather and climate element in different manner depend on his physical condition, age, food and culture. People who lives in hot dessert area would will be more insensitive agains hot and dry sand, thus they could comfortly walk on it without shoes. On the contrary, people who lives in cold region could comfortly walk on the snow.

Some researhers (Thom, 1959; Kawamura, 1965; Epstein and Moran, 2006) developed methods for determining the human confort by some sets of equation which included two or more wheater and climate elements. One of the methods was discomfort index which sometime called as temperature-humidity index since its main variables were temperature and RH. Discomfort index provides measurement for discomfort feeling of labor in his working place.

Discomfort index is promoted empirically based on human culture and environment condition, thus the index criteria may be different for each specific location. In addition to discomfort index, US National Oceanic and Atmospheric Administration classified working place discomfort by its heat index (NOAA, 2014). Heat index combine temperature and RH effect toward body heat loss. The most comfortable condition is perceived, when body heat loss is in the same rate with the thermal produced by metabolism process and environment condition. Heat index was adopted by US Department of Labor, Occupational Safety and Health Administration for imposing labor protection standard regulation (OSHA, 2014).

Plant in built environment such as residential or office building could affect to its surounding climate and weather elements. The shady plants such as big tree and bamboo clump, shade the surrounding thus the earth's surface receive less short wave of sunrays energy. Since the earth's surface received less sunrays energy, the earth's surface reduces its energy release into the atmosphere, thus the temperature is down and the air becomes cooler and more comfortable. The temperature different in hot and cold season could be reduced by growing pretty much plants in the surrounding. Photosynthesis mechanism of green plant could absorb sunrays energy, reduce CO_2 and produce O_2 which is very important for people. Plants in the surrounding may increase the building value because the occupant's comfortable feeling is rising.

This study was conducted to measure the daily cycle of climate and weather element limited to sunlight intensity, temperature and RH inside bamboo stand and in open space nearly office environment. The measurement of occupant's comfort feeling in both location was determined by discomfort index and heat index. The study proposed period of time, when labor could comfortly work inside bamboo stands compared to in open space.

METHODOLOGY

The study was conducted in Bogor Agricultural University (IPB). Environmental variables namely sunlight intensity, temperature and RH were periodically measured within two months (10 Februari-22 Maret 2013) inside bamboo stand in arboretum and in open space (field for flag ceremony). Apparatus for measuring those variable was Environment meter Krisbow KW06-291.

Sunlight intensity: Daily cycle of sunlight intensity outside and inside bamboo stands were estimated by four types of equation namely sine, exponential-sine, power-sine and logarithmic-sine as seen on Eq. 1-4. The basic calculations method were regression analysis model (linear, exponential, power and logarithmic) where the independent variable was the sine of time. As a function of the sine of time, the result should be wave equations. Since the earth's surface receives the sunlight in daytime only, the wavelength of wave equation should be related to the length of the day. The best equation among them is choosen by the highest value of coefficient of determination (R^2).

Sine:

$$\hat{I} = a\sin\left(\pi\left(t - t_0\right)/L\right) - b \tag{1}$$

Exponential-sine:

$$\hat{I} = a\exp\left(b\sin\left(\pi\left(t - t_0\right)/L\right)\right) \tag{2}$$

Power-sine:

$$\hat{I} = a\left(\sin\left(\pi\left(t - t_0\right)/L\right)\right)^b \tag{3}$$

Logarithmic-sine:

$$\hat{I} = a\ln\left(\sin\left(\pi\left(t - t_0\right)/L\right)\right) + b \tag{4}$$

Where:

$\hat{I}$ = Sunlight intensity (lux)
a, b = Regression coefficients
t = Time of measurement (hour) (GMT+7)
t_0 = Sunrise time (hour) (GMT+7)
L = Length of the day (hour)

Time of measurement, sunrise and length of the day were tranformed become decimal number, for example 06:15 become 6.25, 12:30 become 12.5 and 18:45 become 18.75.

Temperature and relative humidity: Daily cycle of temperature and relative humidity outside and inside bamboo stands were affected by two variables namely sunrays radiation and earth's surface energy. Equation 5-8 were proposed to fit the daily cycle of temperature and RH based on both effects:

$$y = a + b\sin\left(\frac{\pi}{12}\left(t - t_0 - k_1\right)\right) + cz\sin\left(\frac{\pi}{L}\left(t - t_0 - k_2\right)\right) \tag{5}$$

$$y = a + b\sin\left(\frac{\pi}{12}\left(t - t_0 - k_1\right)\right) + cz\exp\left(\sin\left(\frac{\pi}{L}\left(t - t_0 - k_2\right)\right)\right) \tag{6}$$

$$y = a + b\exp\left(\sin\left(\frac{\pi}{12}\left(t - t_0 - k_1\right)\right)\right) + cz\sin\left(\frac{\pi}{L}\left(t - t_0 - k_2\right)\right) \tag{7}$$

$$y = a + b\exp\left(\sin\left(\frac{\pi}{12}\left(t - t_0 - k_1\right)\right)\right) + cz\exp\left(\sin\left(\frac{\pi}{L}\left(t - t_0 - k_2\right)\right)\right) \tag{8}$$

Where:

y = Temperature (T) (°C) or Relative Humidity (RH) (%)
a, b, c = Regression coefficient
z = Dummy variable (binary number which the value is 0 at night and 1 at daytime)
t = Time of measurement (hour) (GMT+7)
t_0 = Sunrise (hour) (GMT+7)
k_1 = Additional phase for earth's surface energy effects (hour) (GMT+7)
k_2 = Additional phase for sunrays radiation effects (hour) (GMT+7)
L = Length of the day (hour)

Estimation for additional phase for earth's surface energy effects and sunrays radiation effects (k_1 dan k_2) conducted by the methods bellow.

Estimation for additional phase for earth's surface energy effects (k_1): The cycle of temperature and RH at night are only affected by earth's surface energy because there are not any sunrays, thus Eq. 9 and 10 was proposed to estimate the earth's surface energy effect based on data which measured in the night only. In this step, data which were measured during daytime were not used. The best estimated value for k_1 was choosen by iteration methods which minimizing the sumsquare of residuals. Minimizing the sumsquare of residual has the same meaning with maximizing the coefficient of determination:

$$y = a + b\sin\left(\frac{\pi}{12}(t - t_0 - k_1)\right) \tag{9}$$

$$y = a + b\exp\left(\sin\left(\frac{\pi}{12}(t - t_0 - k_1)\right)\right) \tag{10}$$

Estimation for additional phase for sunrays radiation effects (k_2): Temperature and RH in daytime are affected by the combination of sunrays radiation and earth's surface energy. If it is assumed that the net energy released by earth's surface in the night is in similar quantity with the absorbed energy during the corresponding daytime, the best estimation of k_1 which resulted from Eq. 9 and 10 should be used for both night and daytime. Then Eq. 5-8 were used to estimated the daily cycle of temperature and RH based on the combination of sunrays radiation and earth's surface energy. Estimation for additional phase for sunrays radiation effects were conducted by iteration method which minimizing the sumsquare of residuals. All data measured in night and daytime were used in this step. The best one among those four equations was choosen by the highest coefficient of determination and the smallest standard deviation. Based on the best equations, then curve estimations were drawn in Cartesian diagram in the same sheet with the observed data.

Discomfort index and heat index: Thom (1959) introduced discomfort index which is calculated by Eq. 11-12. The United States government adopted the discomfort index and classified the value as seen on Table 1:

$$IT = 0.4\ (T + T_d) + 15 \tag{11}$$

$$IT = T-0.55\ (1-0.01R)\ (T-58) \tag{12}$$

Table 1: Thom's Discomfort Index (DI) classification

DI value	Condition
<70	No one feels discomfort
70-75	Few people feel discomfort
75-80	A half people feel discomfort
>80	Most people feel discomfort

Table 2: US NOAA heat index classification

	Temperature (°F)															
	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
Relative humidity (%)																
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Note; 80-90: Caution, 91-103: Extreme caution, 104-124: Danger, 125 and above: Extreme danger

Where:
IT = Discomfort index
T = Temperature (°F)
T_d = Dew point temperature (°F)
R = Relative humidity (%)

The best equation for estimate the daily cycle of temperature and RH which resulted from Eq. 5-8, were substituted into Eq. 12 to calculate the discomfort index value outside and inside bamboo stands as a function of time. Equation for temperature were modified from Celcius scale become Fahrenheit scale. Ranges of discomfort index were drawn in Cartesian diagram coincides with its curve which drawn based on its function of time, thus the period of discomfort within each day was estimated.

In addition to Thom's discomfort index, the heat index was calculated according to Eq. 13. Heat index has been adopted by US National Oceanic and Atmospheric Administration since 1979 until now (NOAA, 2014).

$$HI = c_1 + c_2T + c_3R + c_4TR + c_5T^2 + c_6R^2 + c_7T^2R + c_8TR^2 + c_9T^2R^2 \quad (13)$$

where, HI is Heat index, T is temperature (°F), R is relative humidity (%), c_1 = -42.379, c_3 = 10.1433, c_5 = -6.83783×10^{-3}, c_7 = 1.22874×10^{-3}, c_9 = -1.99×10^{-6}, c_2 = 2.0949, c_4 = -0.22475541, c_6 = -5.481717×10^{-2} and c_8 = 8.5282×10^{-4}.

Heat index values were intrepeted and classified into Table 2. Heat index combines air temperature and RH to determine equivalent temperature which is felt by human skin. This heat index value is well known as apparent temperature or felt air temperature.

RESULT AND DISCUSSION

Sunlight intensity: Sun is major energy resource for every life thing in earth. In addition to that, the changes and movements in earth atmosphere were commonly affected by the sun energy, thus sun should be considered as the major controller of climate and weather. Length of the day which is defined as the length of the sunshine in certain location, varies depend upon the latitude of the location. This variation is caused by the angle of earth rotation axis to the ecliptical plane of earth's orbit during its revolution surrounding the sun. Because of that angle, the sun looks like moving from 23.5 °NL to 23.5 °SL in a half year and turn into reverse direction in the next half year. In equator length of the day is not exactly 12 h but 12 h 7 min in average because of the sun dimension and sunlight refraction by the atmosphere. Some websites provide length of the day data for certain location, e.g., http://www.timeanddate.com. According to this website, length of the day, sunrise and sunset time in Bogor during this study was shown in Table 3. The shortest length of the day during the study period is 12 h 5 min and 54 sec, while the longest is 12 h 20 min and 21 sec. The sunrise is at 5:57-5:58, while the sunset is at 18:03-18:17.

The sunlight energy is reduced by atmosphere before it reaches the earth's surface. Some of the sunlight energy is absorbed by water vapor, O_2, O_3 and CO_2, scattered by small size particles which their dimension is smaller than sunlight wavelength and reflected by cloud and other particles which their dimension is bigger than sunlight wavelength. The quantity of sunlight intensity is highly correlated with human health and comfort. Fonn (2011) and Cullen (2002) reported that strong Ultra Violet (UV) radiation of sunlight caused skin burn and conjunctivis. Conjuctivis is eye disease which its conjunctiva inflammes, the symptoms are the eye color is red and it feels poignant when exposed to the sunlight. Harper *et al.* (2008) reported that eye could suffer biological disorder such as photo keratitis and erythema if exposed to strong UV radiation from the sunlight or artificial light. Pechacek *et al.* (2008) reported than light is major cue from surounding condition which control the beginning of human hearth beat, light is endogenous clock for hypothalamus which control the human physiological rhythm and habit. The insufficient or excessive light intensity arises hearth beat rhythm disorder which disturb the human performance, health and safety. Sunlight intensity which is received by earth's surface should be measured in lux scale.

Table 3: Length of the day, sunrise and sunset time in Bogor during the study period

Date	Sunrise (t_0)	Sunset	Length of the day (L) (h)	(min)	(sec)
10-Feb-13	5:57	18:17	12	20	21
11-Feb-13	5:57	18:17	12	20	01
12-Feb-13	5:57	18:17	12	19	41
13-Feb-13	5:57	18:17	12	19	20
14-Feb-13	5:58	18:17	12	18	59
20-Feb-13	5:58	18:15	12	16	52
22-Feb-13	5:58	18:15	12	16	09
9-Mar-13	5:58	18:09	12	10	40
10-Mar-13	5:58	18:08	12	10	18
11-Mar-13	5:58	18:08	12	09	56
20-Mar-13	5:57	18:04	12	06	37
21-Mar-13	5:57	18:03	12	06	16
22-Mar-13	5:57	18:03	12	05	54

http://www.timeanddate.com

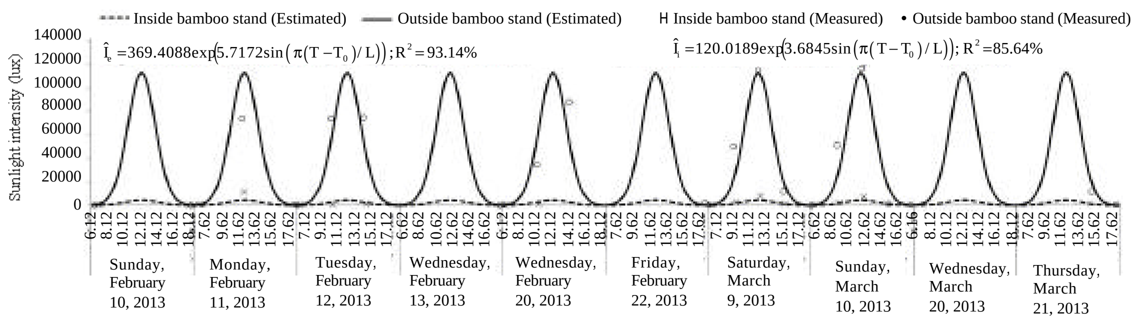

Fig. 1: Sunlight intensity outside and inside bamboo stands follows the exponential-sine curve

Table 4: Regression analysis model for fitting the sunlight intensity (lux) outside and inside bamboo stand

	Outside bamboo stand (n = 24)		Inside bamboo stand (n = 19)	
	Model	R^2	Model	R^2
Linear	$\hat{I}_o$ = 84696.86 sin (π(T-T_0)/L)-6296.86	78.09	$\hat{I}_i$ = 6359.25 sin (π(T-T_0)/L)-1181.77	47.89
Exponential	$\hat{I}_o$ = 369.4088 exp (5.7172 sin (π(T-T_0)/L))	93.14	$\hat{I}_i$ = 120.0189 exp (3.6845 sin (π(T-T_0)/L))	85.64
Power	$\hat{I}_o$ = 5.364.78 (sin (π(T-T_0)/L))$^{1.3807}$	79.93	$\hat{I}_i$ = 3374.2138 (sin (π(T-T_0)/L))$^{1.3729}$	78.60
Logarithmic	$\hat{I}_o$ = 19714.47 In (sin (π(T-T_0)/L))+65377.11	62.25	$\hat{I}_i$ = 2160.38 In (sin (π(T-T_0)/L)+4396.98	36.54

In the morning, the sunrays arrives in oblique angle thus earth's surface area which receive the sunlight is wider. The angle will be gradually higher until perpendicular at the mid day and lower afterwards. Since the minimum area is happened in the mid day, the sunlight intensity is maximum in the mid day. According to the measurement during two months, it was proved that the daily cycle of sunlight intensity is following the exponential-sine equation. Exponential-sine curve estimation revealed highest coefficient of determination among others (sine, power-sine and logarithm-sine). It gained 93.14 and 85.64% coefficient of determination for daily cycle of sunlight intensity outside and inside bamboo stands, respectively. The detail equations were tabulated in Table 4. Since their highest coefficient of determination, exponential-sine equations were choosen for drawing the sunlight intensity curves in Cartesian diagram for both outside and inside bamboo stands. The curves were shown in Fig. 1.

Figure 1 reveals that sunlight intensity curve inside bamboo stands has much lower peak value than in open space. Bamboo clumps shadow reduce the sunlight intensity thus the maximum value become 4780 lux. It was much lower compared to 112300 lux which was gained in open space. Human eye could process the light illumination from 1 lux until 100000 lux. Reinhart *et al.* (2006) conducted the study on human comfort, when working in daytime and exposed by several level of illumination and reported that the comfort feeling could be gained when the illumination level was 100-2000 lux. The room was too dark when the illumination level bellow 100 lux. If the illumination level was higher than 2000 lux the labors felt visual discomfort and probably some thermal discomfort. Based on Reinhart's illumination classification, the sunlight intensity curve was classified into two zones namely comfort and discomfort zone as seen on Fig. 2. In accordance with Fig. 1, it was shown that outside bamboo stands was dominated by discomfort zone. At 07:15-17:00 labors who work in open space felt visual discomfort. While visual discomfort would be felt at 09:30-14:45 inside bamboo stand. The visual comfort feeling last longer inside bamboo stands than in open area.

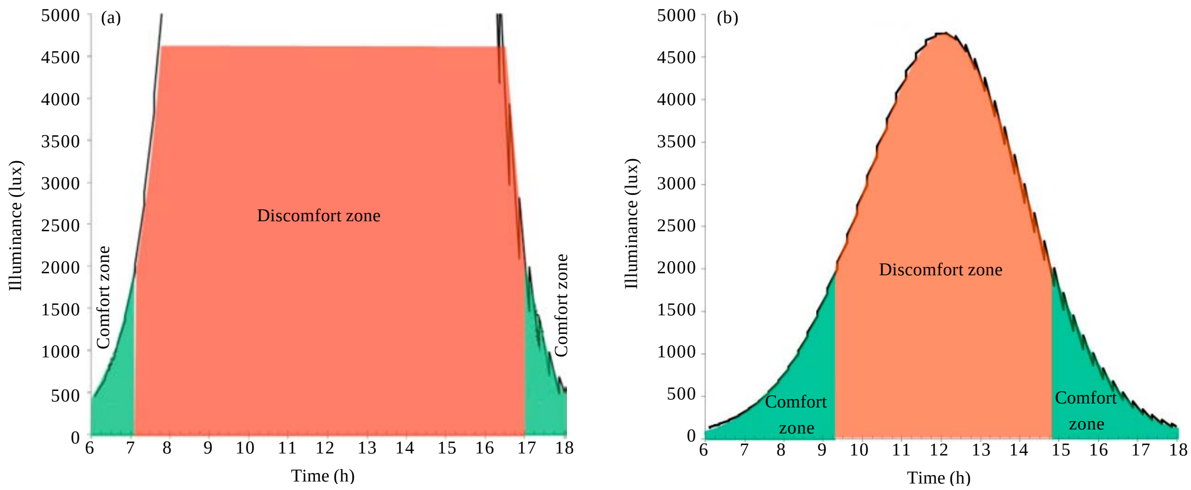

Fig. 2(a-b): Illumination (lux) gained everytime during daytime, (a) Outside and (b) Inside of bamboo stands, coincided with Reihart's classification

Table 5: Fagerhult's luminance classification

Class	Luminance (cd m^{-2})	Description
A	<1000	Average luminance is low, recommended for rooms require anti-glare such as office which stuffed with common monitor
B	1000-3500	Average luminance is low, recommended for general requirement of rooms. Glare risk is low
C	3500-5000	Average luminance is high enough. Glare risk may be reduced if the surrounding luminance is high
D	>5000	Average luminance is very high. The glare still attack the eye eventhough the surrounding luminance is high too. This level of luminance should be avoided.

Inspite of illuminance, there is another quantity measurement of lighting namely luminance. Luminance is the ammount of light emitted by a surface. Luminance measures the brightness of a surface which received by human eye. Exact mathematical relation between luminance (L_v) and illumination (E_v) is shown in Eq. 14:

$$E_v = \pi L_v \tag{14}$$

Where:
E_v = Illumination (lux)
L_v = luminance (candela/m^2)

Fagerhult (2014) developed classification system for determining the average luminance of a surface (Table 5). There are four categories namely A, B, C and D in Fagerhult's classification, thus it has wider range and more detail than Reinhart's. Based on Fagerhult's classification it was revealed that in open space the luminance was vary and the D class was dominant (Fig. 3a). At 08:45-15:30, earth's surface reflects sunlight in higher intensity thus most people would have glare feeling when seeing it. The C class in open space was happen in the short time that is 08:30-08:45 and 15:30-15:45. In the C class zone the glare was appearing. The visual comfort feeling which is indicated by A and B class, was happened in 2.5 h length each in the morning after sunrise and

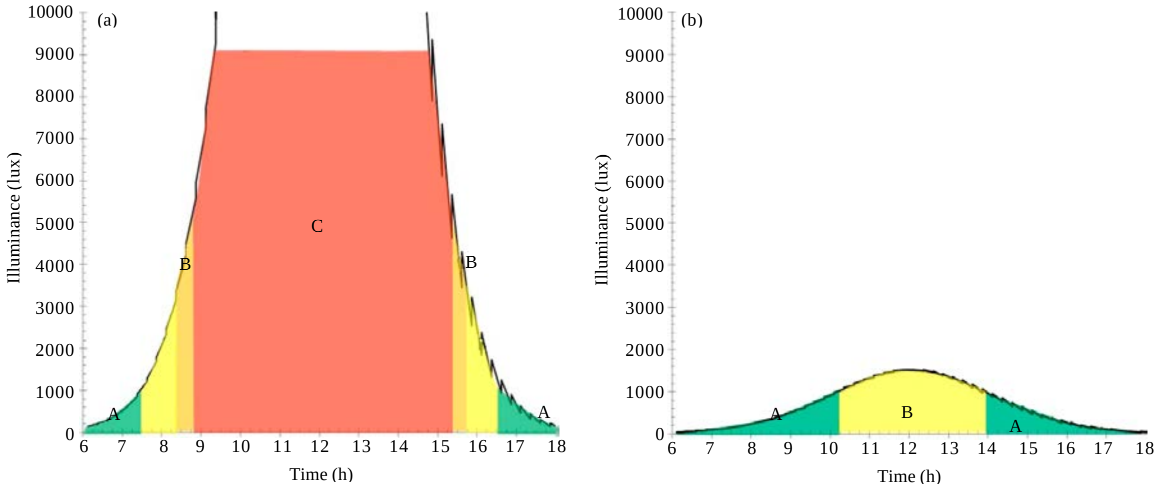

Fig. 3(a-b): Luminance (candela/m^2) gained everytime during daytime, (a) Outside and (b) Inside of bamboo stands, coincided with Fagerhult's classification

in the afternon before sunset. While inside bamboo stand, there were many shadows thus the maximum luminance was 1422 candela/m^2. Luminance inside bamboo stand was in A and B class during all day long (Fig. 3b). It means, most people would be in visual comfort every time because his eye would never feel glare inside bamboo stands.

Temperature and relative humidity: Sun is the major thermal energy resource for the earth. Sun releases electromagnetic wave to overall direction in 3×10^{10} cm sec^{-1} speed. The radiation is reduced by the atmosphere before reaching the earth's surface. About 35% of the radiation is emmited to the outer space, penetrated the upper limit of the atmosphere by the reflection and scattering mechanism of cloud, dust particle, air molecules and earth's surface, about 14% is absorbed by the atmosphere and the rest (51%) is received by earth's surface (Tjasyono, 1998). Then the earth's surface emittes the thermal energy into the atmosphere in longwave radiation form. So the air temperature in certain location is affected by two main factors namely sunrays radiation and earth's surface energy.

During the night, sunrays radiation effect value could be assumed zero because there is not any sunrays, thus the air temperature must be affected by earth's surface energy only. This phenomenon opens the possibility to estimate the additional phase for earth's surface energy (k_1) using the temperature and RH during the night only. As seen on Fig. 4, the maximum coefficient of determination (R^2) for sine model was gained when the k_1 value for temperature outside and inside bamboo were 5.5 and 2.6, respectively while for exponential-sine model were 5.85 for outside and 2.6 for inside. For RH outside and inside bamboo stand, it was concluded that the best estimation for sine model were 5 and 2.3 and for exponential-sine model were 4.65 and 2.1. Those values were used for the next step that was estimating the additonal phase for sunrays radiation effect (k_2).

Similar with k_1 estimation, k_2 were estimated by iteration method for maximizing its coefficient of determination. In this step all data (night and daytime) were used. The relation between k_2 and coefficient of determination (R^2) were drawn in Fig. 5 for temperature and Fig. 6 for RH.

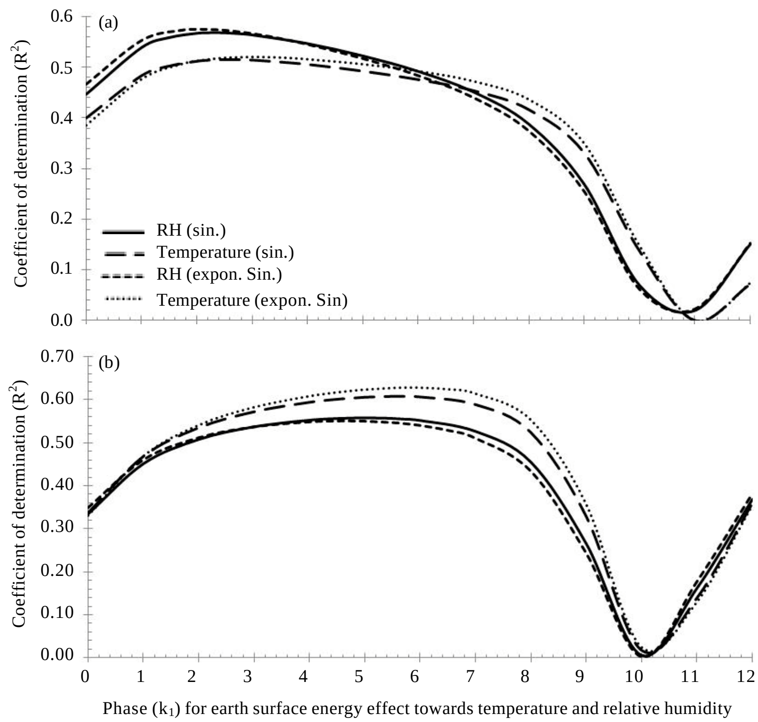

Fig. 4(a-b): Estimation for phase (k_1) for earth's surface energy effect toward temperature and relative humidity, (a) Inside and (b) Outside bamboo stand by maximizing its coefficient of determination

Table 6: Best estimation for temperature Inside (I) and Outside (O) bamboo stand

	Best estimation for temperature										
Model	i/o	k_1	k_2	a	b	c	Multiple R	R^2	Adj-R^2	s	N
$T=a+b\sin\left(\frac{\pi}{12}(t-t_0-k_1)\right)+cz\sin\left(\frac{\pi}{L}(t-t_0-k_2)\right)$	i	2.60	1.280	25.92	2.07	3.86	91.79	84.26	83.28	1.28	35
	o	5.50	10.860	26.19	2.72	-5.93	87.21	76.06	74.61	1.55	36
$T=a+b\sin\left(\frac{\pi}{12}(t-t_0-k_1)\right)+cz\exp\left(\sin\left(\frac{\pi}{L}(t-t_0-k_2)\right)\right)$	i	2.60	2.320	25.80	2.52	1.28	89.92	80.85	79.66	1.41	35
	o	5.50	-0.600	25.36	1.50	2.29	83.67	70.01	68.20	1.73	36
$T=a+b\exp\left(\sin\left(\frac{\pi}{12}(t-t_0-k_1)\right)\right)+cz\sin\left(\frac{\pi}{L}(t-t_0-k_2)\right)$	i	3.00	0.620	23.41	1.86	3.98	91.31	83.38	82.34	1.32	35
	o	5.85	11.030	22.92	2.36	-6.80	88.27	77.92	76.58	1.48	36
$T=a+b\exp\left(\sin\left(\frac{\pi}{12}(t-t_0-k_1)\right)\right)+cz\exp\left(\sin\left(\frac{\pi}{L}(t-t_0-k_2)\right)\right)$	i	3.00	0.705	22.82	2.31	1.21	89.64	80.35	79.13	1.43	35
	o	5.85	-0.150	24.12	0.90	2.39	82.21	67.58	65.62	1.80	36

Finally the best estimation for each model were choosen and tabulated in Table 6 and 7. Among four models, the best equation for temperature inside bamboo stand was Eq. 15; for temperature in open space was Eq. 16; for RH inside bamboo stands was Eq. 17 and for RH outside bamboo stands was Eq. 18. Equation 15 and 16 were drawn become Fig. 7 while Eq. 17 and 18 were drawn become Fig. 8:

$$T=25.92+2.07\sin\left(\frac{\pi}{12}(t-t_0-2.6)\right)+3.86z\sin\left(\frac{\pi}{L}(t-t_0-1.28)\right) \tag{15}$$

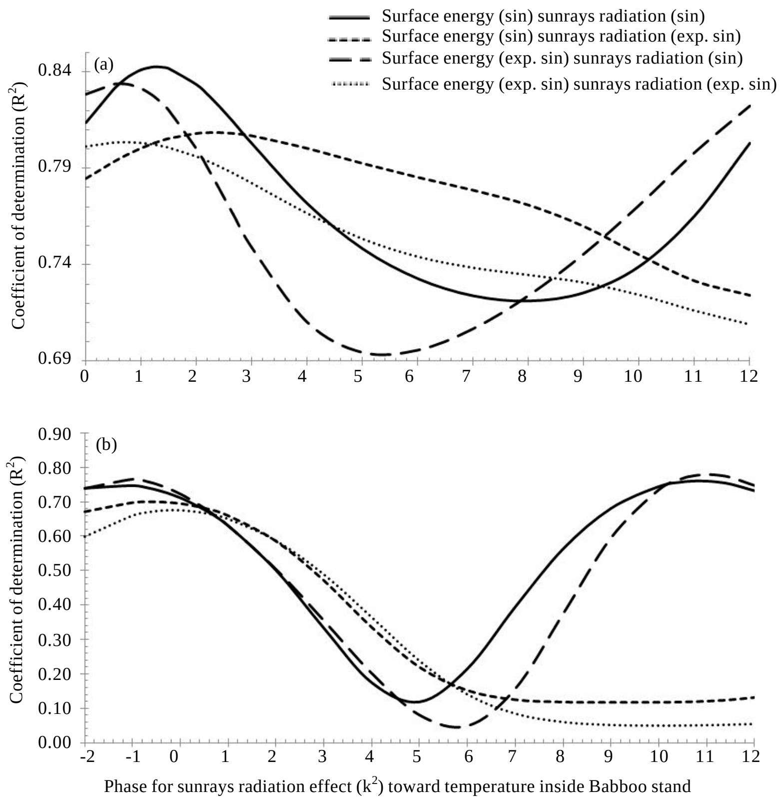

Fig. 5(a-b): Estimation for phase (k_2) for sunrays radiation effect toward temperature, (a) Inside and (b) Outside bamboo stand by maximizing its coefficient of determination

Table 7: Best estimation for relative humidity Inside (I) and Outside (O) bamboo stand

Model	Best estimation for relative humidity										
	i/o	k_1	k_2	a	b	c	Multiple R	R^2	Adj-R^2	s	N
$RH = a + b\sin\left(\frac{\pi}{12}(t - t_0 - k_1)\right) + cz\sin\left(\frac{\pi}{L}(t - t_0 - k_2)\right)$	i	2.35	1.14	81.45	-11.25	-11.60	89.86	80.75	79.55	6.04	35
	o	5.00	10.60	78.98	-16.16	25.58	81.85	66.99	64.99	9.78	36
$RH = a + b\sin\left(\frac{\pi}{12}(t - t_0 - k_1)\right) + cz\exp\left(\sin\left(\frac{\pi}{L}(t - t_0 - k_2)\right)\right)$	i	2.35	3.00	82.00	-12.00	-4.50	89.49	80.09	78.85	6.14	35
	o	5.00	-0.74	83.40	-9.18	-10.43	79.29	62.87	60.62	10.37	36
$RH = a + b\exp\left(\sin\left(\frac{\pi}{12}(t - t_0 - k_1)\right)\right) + cz\sin\left(\frac{\pi}{L}(t - t_0 - k_2)\right)$	i	2.10	0.20	95.80	-12.30	-5.90	89.11	79.41	78.13	6.24	35
	o	4.65	10.21	98.79	-15.66	26.37	84.59	71.55	69.83	9.08	36
$RH = a + b\exp\left(\sin\left(\frac{\pi}{12}(t - t_0 - k_1)\right)\right) + cz\exp\left(\sin\left(\frac{\pi}{L}(t - t_0 - k_2)\right)\right)$	i	2.10	-0.10	96.70	-13.20	-1.60	88.95	79.12	77.82	6.29	35
	o	4.65	-0.60	92.65	-7.50	-10.22	79.05	62.49	60.22	10.42	36

$$T = 22.92 + 2.36\exp\left(\sin\left(\frac{\pi}{12}(t - t_0 - 5.85)\right)\right) - 6.8z\sin\left(\frac{\pi}{L}(t - t_0 - 11.03)\right) \quad (16)$$

$$RH = 81.45 - 11.25\sin\left(\frac{\pi}{12}(t - t_0 - 2.35)\right) - 11.60z\sin\left(\frac{\pi}{L}(t - t_0 - 1.14)\right) \quad (17)$$

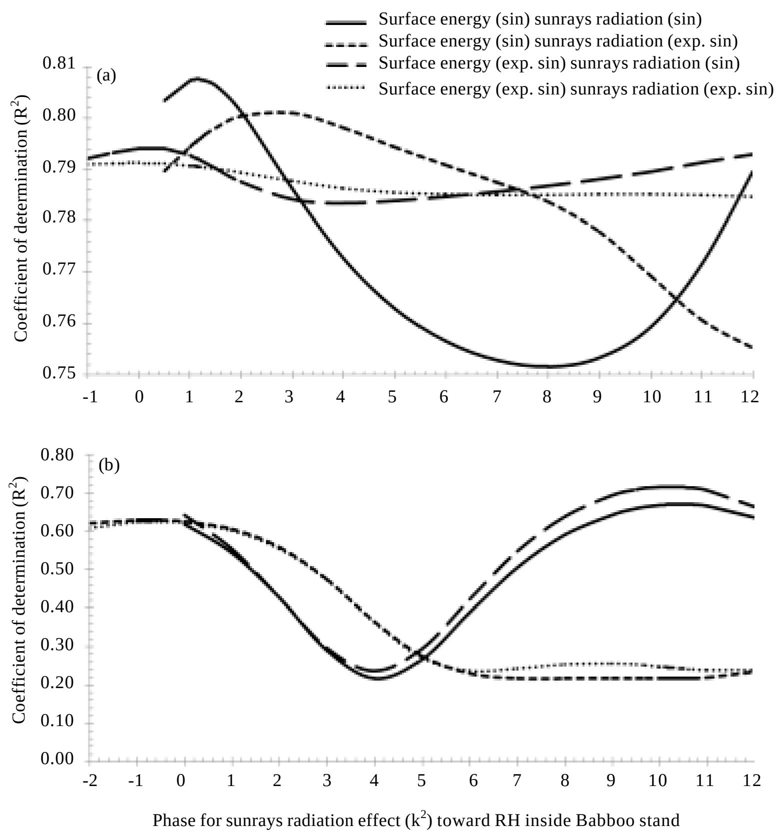

Fig. 6(a-b): Estimation for phase (k_2) for sunrays radiation effect toward relative humidity, (a) Inside and (b) Outside bamboo stand by maximizing its coefficient of determination

$$RH = 98.79 - 15.66\exp\left(\sin\left(\frac{\pi}{12}(t - t_0 - 4.65)\right)\right) + 26.37\,z\sin\left(\frac{\pi}{L}(t - t_0 - 10.21)\right) \quad (18)$$

Air temperature is main factor affected to the human comfort in certain location. Air temperature directly related to the body heat transfer (conduction, convection and radiation) and evaporation to balance the body temperature. Physiological interpretation for the most comfort surrounding temperature is when the thermal balance is reached with minimum work of the body. Human feel uncomfort when body need to work hard to reach the thermal balance condition. In comfort condition, thermal which is produced by the metabolism mechanism is in the same rate with thermal transfer and evaporation from the body to the surrounding thus body doesn't need to run the excessive thermal control mechanism. When in comfort condition, the body works in maximum efficiency and the mind and emotion are calm. Maximum productivity is commonly gained in this comfort condition, while accident probability is rising when the air temperature is higher or lower (Mohamed and Srinavin, 2002).

Air temperature is vary in different height. Bradshaw (2010) reported that the ideal air temperature in 0-180 cm height from earth surface (floor) is 17-29°C. This comfort air temperature range was happened in 13 h length (19:00-08:00) in open space and in the rest time (08:00-19:00)

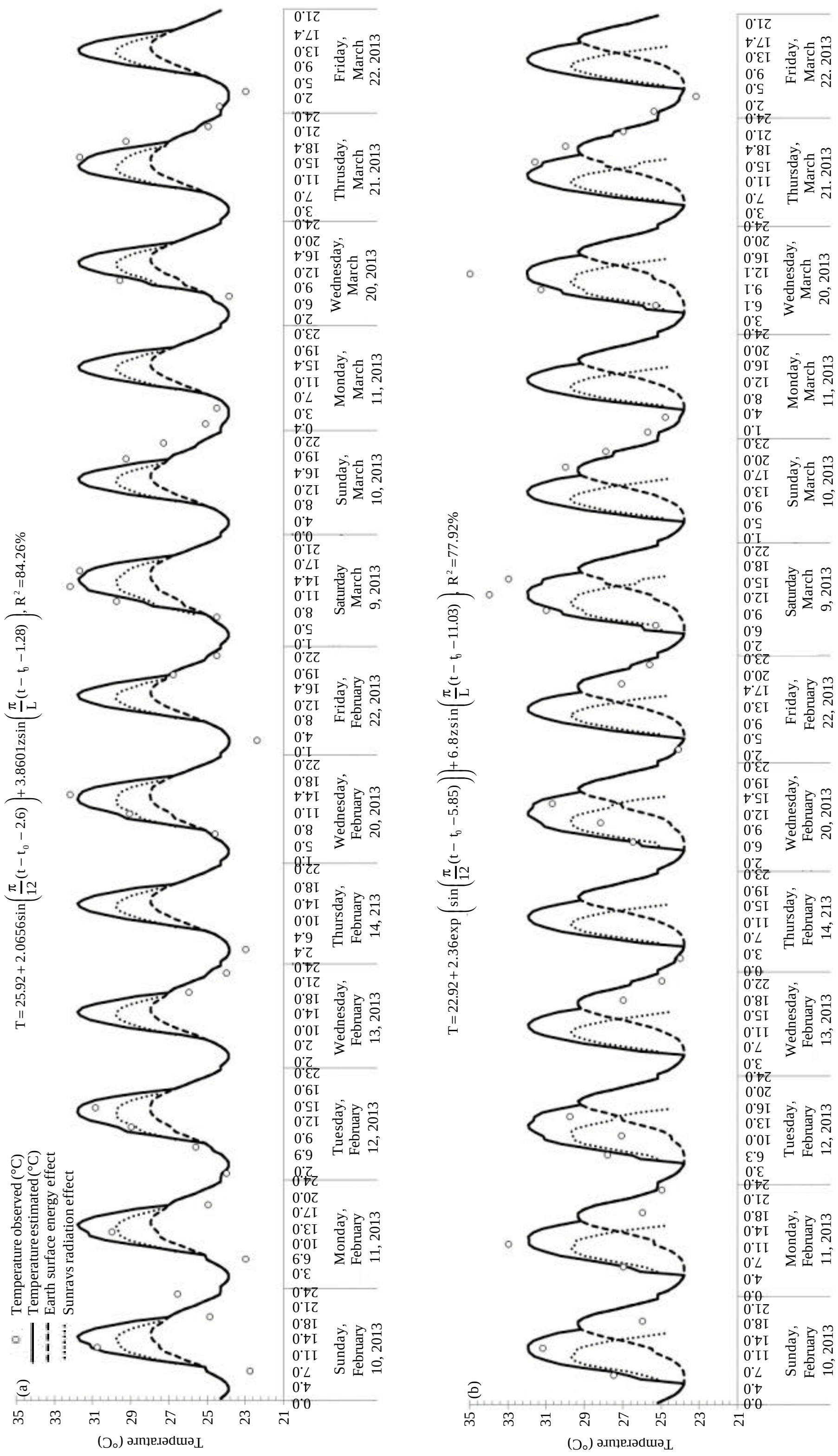

Fig. 7(a-b): Best estimation for daily temperature cycle, (a) Inside and (b) Outside bamboo stand

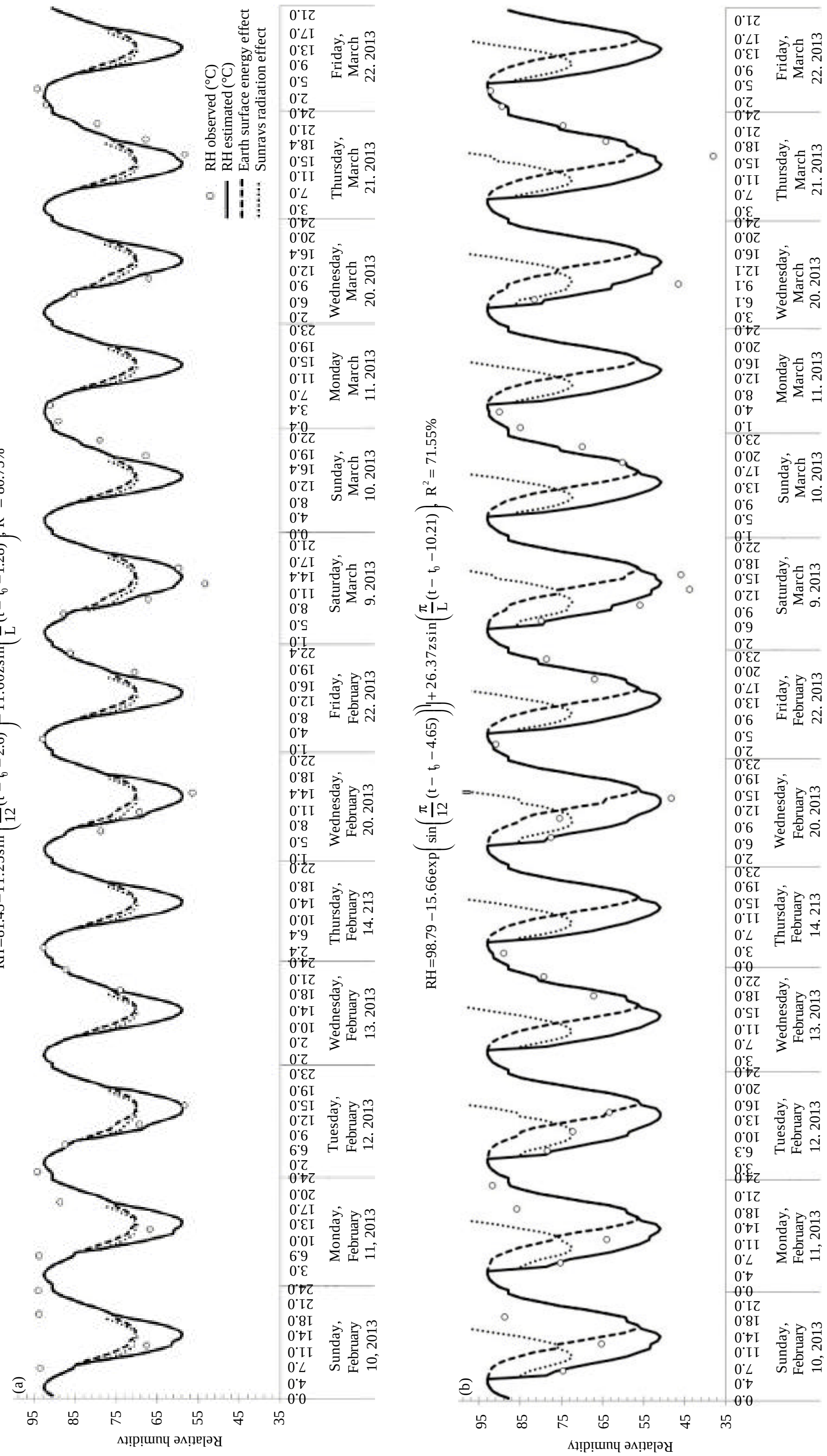

Fig. 8(a-b): Best estimation for daily relative humidity cycle, (a) Inside and (b) Outside bamboo stand

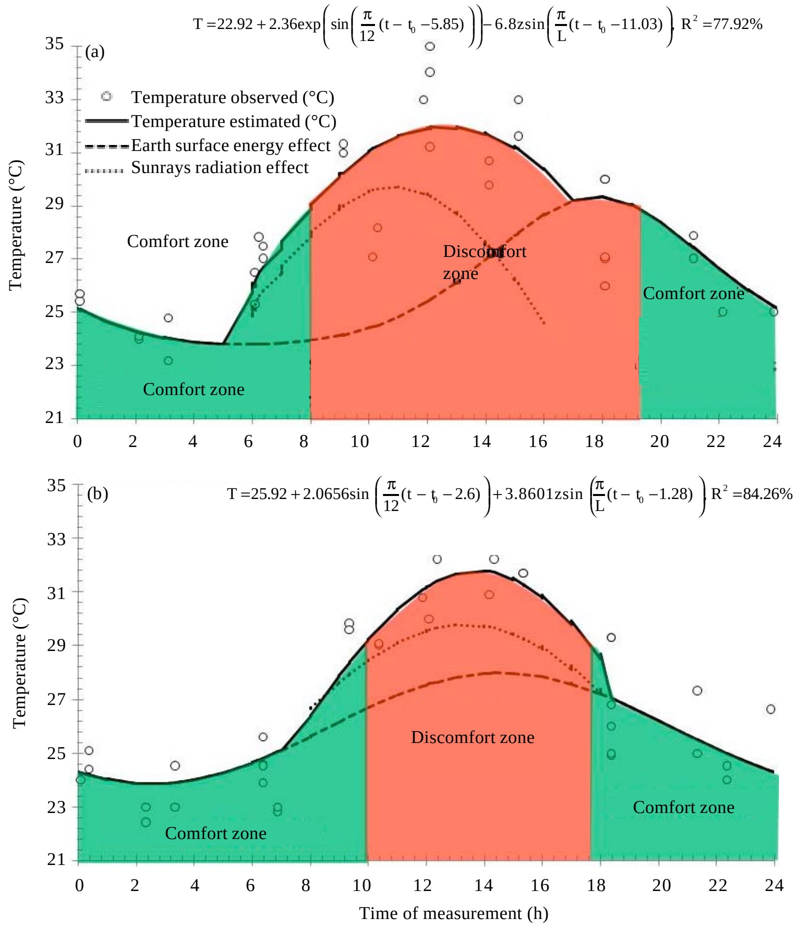

Fig. 9(a-b): Temperature (a) Outside and (b) Inside of bamboo stand, coincide with its discomfort classification

the air temperature is higher than 29°C. The comfort air temperature inside bamboo stand was last longer than in open space (Fig. 9). The ideal air temperature inside bamboo stands was gained in 16.5 h length (17:30-10:00). Labor was safe from heat inside bamboo stands, thus they could comfortly work 3.5 h longer. The shady bamboo culms block the sunrays radiation thus earth's surface receives it in reducing quantity. The hotter surrounding causes the increasing load of human hearth, since the hearth must beat more rapidly to pump the blood in order to flow to all of the body in faster rate. In hotter surrounding, body temperature commonly higher because the heat transfer mechanism (conduction, convection and radiation) from the body to the surrounding is naturally happened in slower rate. Perspiration evaporation by vaporizing the sweat is the only mechanism could be done to cooling down the human body in hot surrounding. The perspiration evaporation is responsible for most amount of body heat loss. In addition to that mechanism, a small amount of body heat loss is caused by continuous activity of lungs and respiratory tracts which vaporize the water from inside human body. If this heat loss rate is too fast, people feel lassitude and attract mentall dullness since the blood flow directly from the hearth to the outer blood vessel and turning back into hearth without passing the brain and some other organs (Bradshaw, 2010). Hot surrounding air may cause dehydration and metabolism disorder. The diseases related to heat often rise in summer or in tropic (Tjasyono, 1998).

In cold surrounding, human body blocks the heat loss adapted by narrowing the outer blood vessel to reduce the blood flow rate into the skin. This mechanism promotes the skin become thermal insulation between inner body and the surrounding. If the body thermal loss is still too high in cold condition, body will tremble and muscular may move uncontrollable. This results physical fatique if happened in long time (Bradshaw, 2010). Fortunately, the too cold surrounding was never happened at the both study location during this study.

Besides temperature, air humidity contributes to the discomfort of labor working in certain location. Air humidity is the amount of water vapor in the certain volume of dry air. The ratio of water vapor weight (kg) in the air to the dry air volume (m^3) is absolute humidity (kg m^{-3}). Humidity ratio or specific humidity (kg kg^{-1}) is weight of water vapor in the air compared to the weight of dry air. The water content in the air is function of temperature. In warmer air, the water content is commonly rising. Water content in the air, compared to the maximum water content at certain temperature without causing condensation is called saturation degree. This ratio multiply by 100 is called humidity percentage. The humidity percentage determine the dryness of air. The low percentage value mean air is dry, while the higher value means wetter. Humidity percentage, occasionally misscalled as Relative Humidity (RH). Relative humidity is the ratio of partial stress of water contain in the air compared to the stress of saturated air in dry bulb temperature multiply by 100. Humidity percentage value is similar with relative humidity but they are not exactly identic.

Although, human can tolerate to the humidity variation in longer range than to the temperature, the humidity control in working location is also important. High humidity rises the condensation problem in the surface which block the sweat evaporation and respiration thus the body heat cooling becomes slower. The higher water content reducing the air ability to absorb more water vapor from the skin. RH higher than 70% increasing the probability of mold and wood destroying fungi (Li, 2007), corrosion (Syed, 2006) and any other deteriorations related to water content. Low relative humidity may caused a very disturbing static electrical spark, even caused disaster when there are inflammable gas in the room (Zhang *et al.*, 2013). The low RH may cause crack in the wall paint and shrinkage in the wood furniture and floor. The warm and dry air increase the body loss rate by sweat evaporation mechanism but lower RH attract the laryngitis and cough. Human may have comfort living in long range of RH (20-70%) (Gilmore, 1972) but ideally bellow 60% (Arundel *et al.*, 1986). If RH more than 60% body begin to feel discomfort. During two months measurement, it was found that air in the Bogor was very wet. Maximum RH inside and outside bamboo stands were 95%. Air inside bamboo stand was commonly wetter than in open space. The comfort range of RH (20-70%) was gained in daytime at 07:45-20:15 in open space and at 09:45-18:00 inside bamboo stands (Fig. 10).

Discomfort index and heat index: The combination of temperature and relative humidity give better result to measure the discomfort of labor in the working place. As example: at 24°C temperature and 0% RH, the skin may feel cooler as if 21°C, on the contrary at 24°C and 100% RH the skin may feel hotter as if 27°C. If someone work in high temperature and high RH, body heat transfer rate to the surrounding is reduced since all of heat transfer mechanism (conduction, convection and radiation) and evaporation are blocked. In this condition, wind must blow to the

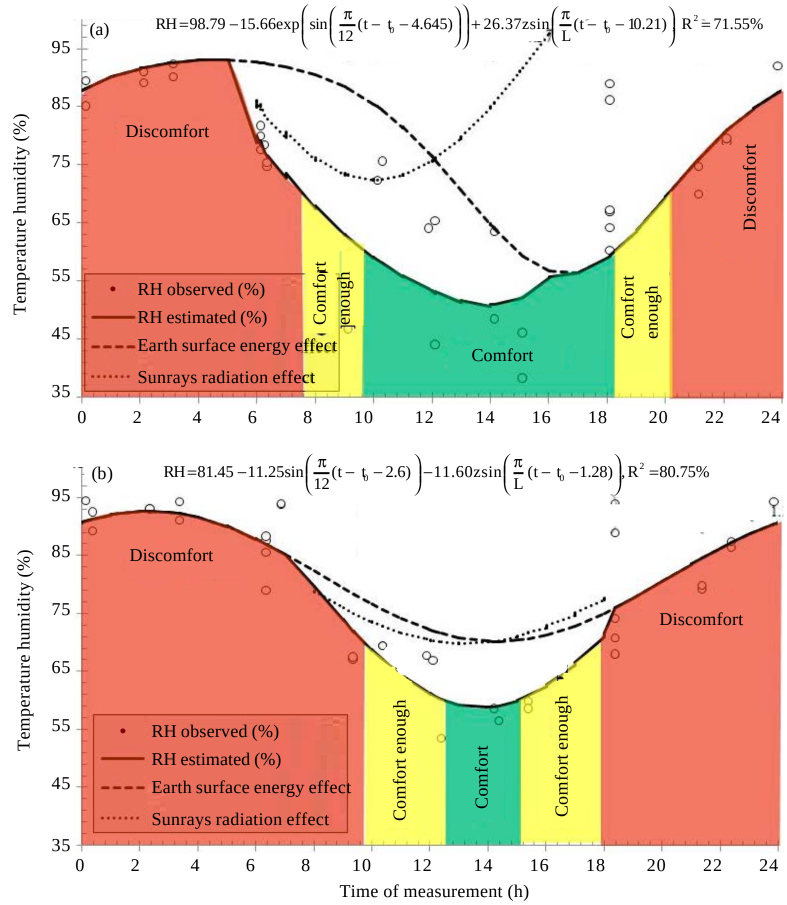

Fig. 10(a-b): Relative humidity, (a) Outside and (b) Inside of bamboo stand, coincide with its discomfort classification

Table 8: Hourly measurement of Thom's discomfort index outside and inside bamboo stands

Discomfort index value	Condition	Outside bamboo stand Period	Outside Length of time (h)	Outside Length of time (%)	Inside bamboo stand Period	Inside Length of time (h)	Inside Length of time (%)
<70	No one feels discomfort	0	0.0	0.00	0	0.0	0.00
70-75	Few people feel discomfort	02:30-05:30	3.0	12.50	00:00-05:30	5.5	22.92
75-80	A half people feel discomfort	05:30-09:30	13.5	56.25	05:30-10:00	11.0	45.83
		16:00-02:30			17:30-24:00		
>80	Most people feel discomfort	08:30-16:00	7.5	31.25	10:00-17:30	7.5	31.25
	Sum		24.0	100.00		24.0	100.00

body to evaporate the sweat and fly it away from the skin. Those two variables are generally used as major variable to calculte the discomfort index. Thom's discomfort index was used in the United States to measure the discomfort of certain working location. Daily cycle of temperature and RH equations in this study were substitute into Thom's discomfort index equation and the result is shown in graphical form (Fig. 11). As seen on Fig. 11 and Table 8, discomfort index value bellow

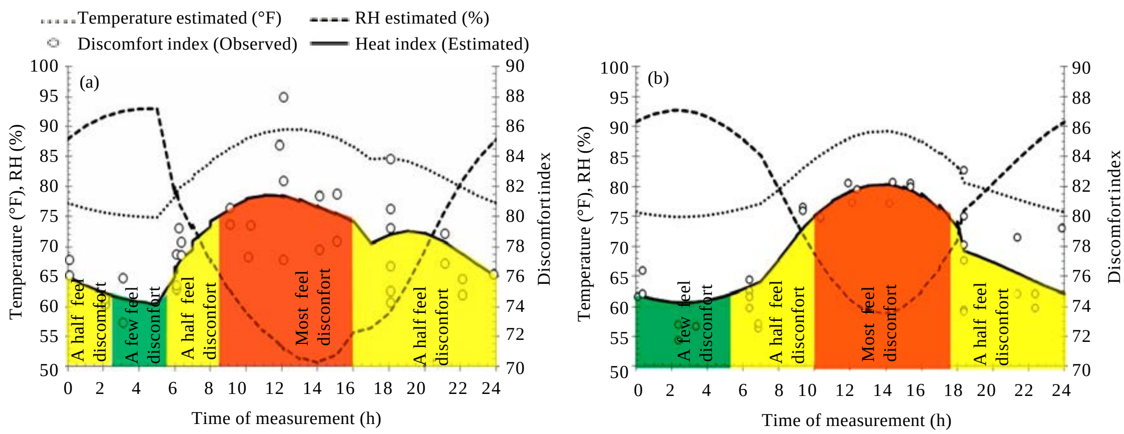

Fig. 11(a-b): Thom's discomfort index, (a) Outside and (b) Inside of bamboo stands and its classification

70 was never gained inside and outside bamboo stands during this study. Discomfort index value 70-75 was gained at 3 h long in open space and 5.5 h long inside bamboo stands; while discomfort index value 75-80 was gained at 13.5 h anf 11 h long outside and inside bamboo stand, respectively. Those phenomenons proved that people feel comfort at 2.5 h longer time inside bamboo stands than in open space. Meanwhile, discomfort index value more than 80 was gained at the similar length of time that was 7.5 h but the periods were different. In open space, the discomfort index value more than 80 was at 08:30-16:00, while inside bamboo stand was at 10:00-17:30. The coincided time between highest discomfort index range with normal working time range in Bogor (08:00-16:00), was 1.5 h longer in open space than inside bamboo space. In the morning, people may work comfortly until 10:00 am inside bamboo stand, while in open space the discomfort feeling was begun at 08:30.

At 1978, George Winterling developed heat index which adopted bu US National Wheater Service since 1979 until now (Bradshaw, 2010). Heat index is also known as humiture or humidex. Heat index measure the effect of both temperature and RH toward the human body heat loss rate to the surrounding. Heat index value is proven more valid than temperature or RH alone in estimating labor's risk agains the heat resources in his surrounding. The higher heat index value, labor would feel hotter air since the sweat cannot easily vaporize to cool the skin. Labors which work outdoor and exposed by hot and humid air (e.g., farmer, fishermen, building construction,etc) or in hot indoor (e.g., cook, electrical and machinary controller, etc) have high risk for thermal related diseases. The risk is rising when the air becomes hotter and wetter. The thermal related diseases (e.g. heat stroke, heat exhaustion, heat cramps and heat rash) attack when body is uncapable releasing body heat in enough rate compared to the heat rate produced by physical activity, metabolism and another heat resources from the surrounding. United Stated Department of Labor, Occupational Safety and Health Administration (OSHA) released practical guidance for worker who work in each certain heat index value (Bradshaw, 2010). The practical guidance was classified into four classes heat index as seen in Table 9. Heat index measurement outside and inside bamboo stands during this study never found danger or extreme danger range (Fig. 12). All measured values were bellow 103, thus the highest risk for labour was exteme caution (moderate). According to OSHA practical guidance, in moderate range, labor should implements prevention plan and increase his awareness. The moderate risk in open space was gained at 14 h long

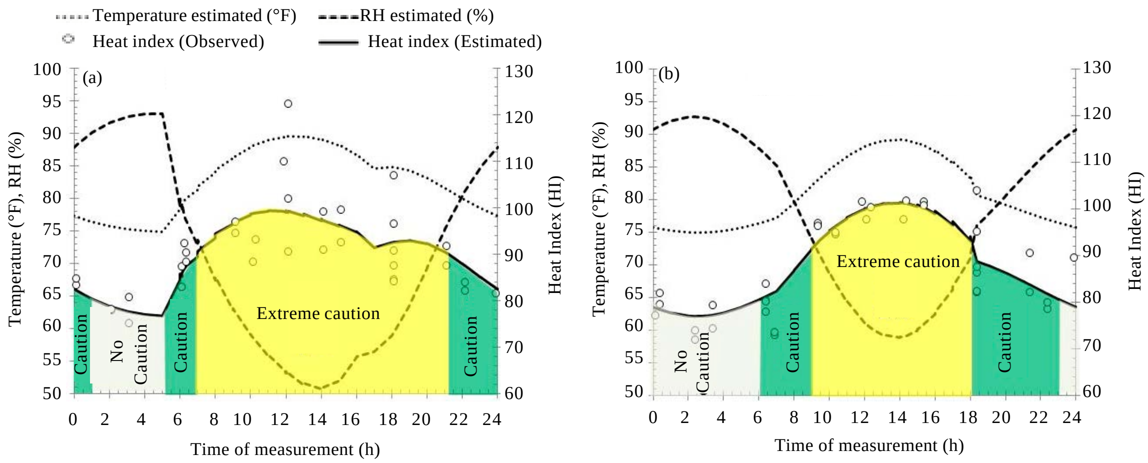

Fig. 12(a-b): Heat Index, (a) Outside and (b) Inside of bamboo stands and its classification

Table 9: Thermal risk level and protective measurement for workers in certain heat index accoring to OSHA practical guidance

Heat index value	Risk level	Protective measures
Less than 91 °F	Lower (Caution)	Basic heat safety and planning
91-103 °F	Moderate	Implement precautions and heighten awareness
103-115 °F	High	Additional precautions to protect workers
Greater than 115 °F	Very high to extreme	Triggers even more aggressive protective measures

Table 10: Hourly heat index measuremen outside and inside bamboo stands

		Outside bamboo stand			Inside bamboo stand		
			Length of time			Length of time	
Discomfort index value	Condition	Period	(h)	(%)	Period	(h)	(%)
<80	No caution	01:00-04:30	3.5	14.58	23:00-06:00	7.0	29.17
80-90	Caution	04:30-07:00	6.5	27.08	06:00-09:00	8.0	33.33
		21:00-01:00			18:00-23:00		
91-103	Extreme caution	07:00-21:00	14.0	58.34	09:00-18:00	9.0	37.50
104-124	Danger	-	0.0	0.00	-	0.0	0.00
>125	Extreme danger	-	0.0	0.00	-	0.0	0.00
	Sum		24.0	100.00		24.0	100.00

(07:00-21:00), while it was 9 h long (09:00-18:00) inside bamboo stands. The rest of the time (21:00-07:00 in open space and 18:00-09:00) was the low risk of heat (Table 10). Thus labor would be safe from heat injury 5 h longer in each day inside bamboo stands than in open space.

CONCLUSION

The daily cycle of sunlight inside and outside bamboo stands in Bogor Agricultural University's arboretum was best fit to the exponential-sine equation than sine, power-sine or logarithmic-sine equation. The visual comfort inside bamboo stand was 4.5 h longer than in open space because bamboo culm shadow blocked the glare of sunlight in daytime. Daily cycle of temperature and RH were affected by sunrays radiation and earth's surface energy. The best equations to fit the daily cycle of temperature and RH based on sunrays radiation and earth's surface energy effects had high coefficient of determination (R^2 = 84.59-91.79%). The comfort zones of temperature (17-29°C) was gained at 13 h long in open space (19:00-08:00); while it was 16.5 h inside bamboo stand (17:30-10:00). RH in both location were high (35-95%); air inside bamboo stand was wetter than in open space. The hourly value of Thom's discomfort index revealed that labor may comfortly work 1.5 h longer inside bamboo stands than in open space during his normal working time. Heat index measurement also revealed that labor was safe from heat injury 5 h longer inside bamboo stand than outside.

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