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A PRELIMINARY STUDY OF A COMFORT INDEX MODEL FOR KUCHING, MALAYSIA

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SINOPSIS

Kertas ini adalah mengenai suhu efektif sebagai suatu petunjuk keselesaan terma bagi Bandar Kuching. Hasil penganalisaan ini menunjukkan bahawa dari segi keselesaan, bulan-bulan Disember dan Januari 1981 didapati berada di bawah paras keselesaan optima, iaitu lebih sejuk, sementara bulan-bulan yang lain, pada keseluruhannya, termasuk dalam lingkungan keselesaan yang boleh diterima. Bulan Mei mempunyai ulangan ketidakselesaan paling tinggi antara tahun-tahun 1968 – 1981 sementara tahun-tahun 1971 dan 1979 masing-masing merupakan tahun yang mempunyai ulangan ketidakselesaan paling rendah dan paling tinggi.

SYNOPSIS

This paper is concerned with effective temperature as an indicator of human thermal comfort with Kucing as illustration. The results of the analysis indicate that the months of December and January 1981 were below the optimum comfort zone implying cooler condition, whereas the rest of the months were within the acceptable comfort limits. The month of May has the highest frequency of heat discomfort for the period 1968 – 1981, whereas the years 1971 and 1979 had the lowest and highest frequency of heat discomfort respectively.

INTRODUCTION

Equatorial climate is known to be warm and humid. And, so far there is no simple solution that can equate the atmospheric interaction with the human body in terms of comfort. The World Meteorological Organisation (WHO) has indicated "the enormous complexity of the bodily functions and the equally complex atmospheric variations defy simple solutions". But research in this field is still going on. A town such as Kuching is growing in area, in population, in technology and no doubt a question arises whether the place is comfortable to live in, or whether the climate is just a factor which man has to cope with.

Over the decades meteorologists and physicists tried to simulate the physiological reaction of the human body by analogy to physical bodies. But the actions an interactions of the weather and the human body are devious in their own sense which only leave rooms for limitations. Therefore, imposing mathematical values on man and his weather leads to controversy, and differences of opinion are inevitable.

PREVIOUS WORKS ON COMFORT INDEX

Recognizing their limitations, several comfort indices have been evolved (mainly due to regional and climatic differences) to assess the effects of cold and heat on human beings. On the warm end of the scale, effective temperature which takes into account temperature, humidity and wind speed proved to be adequate (WMO, 1964). Effective temperature is defined as that temperature of saturated motionless air which would produce the same sensation of warmth or coolness as that produced by the combination of temperature, humidity and air movement under observation. Effective temperature values are lower than the dry bulb temperature.

It was as early as the 1930's that the American Society of Heating and Ventilating Engineers (ASHVE) devised a nomogram for determining effective temperatures for the purpose of air conditioning. The nomogram was adapted by Bedford (1946) and was applied to some Malaysian cities by Ilyas (1980). Thom (1959) proposed an empirical equation for the ASHVE's nomogram to measure discomfort index readily for air conditioning purposes on the basis of available climatic data (Munn, 1970). Modification of Thom's index brought about Kawamura (1965) index to distinguish regional differences of summer climate in Japan, Tennenbaum *et. al.* (1961) index applied to young soldiers marching, then Webb (1960) index for the equatorial region designed for indoor conditions by means of a nomogram. The ASHVE's nomogram was later applied by Stephenson on Singapore, 1963; Watt (1967), on Bahrain; Mcleod (1965) on Gan; Foord (1968) on London; Wycherley (1967), Sham Sani (1977), Ilyas *et. al.* (1981) on Malaysia.

The popularity of the ASHVE nomogram has found its mark world wide, the latest of the nomogram was produced by Weihe (1982) for the WMO Technical Conference on Climate in Africa, The present paper is an attempt to evaluate the effective temperatures as an indicator of thermal comfort for Kuching by means of an equation.

CLIMATIC DATA AND EFFECTIVE TEMPERATURE EVALUATION

The diurnal variations of effective temperature were computed for the period 1968 – 1981 for Kuching. The climatic variables used to calculate the effective temperature are the dry bulb temperature, relative humidity and the surface scalar wind speed which are available on magnetic tapes stored by the Computer Division of the Malaysian Meteorological Service. An equation is derived to evaluate the effective temperatures. The derivation of the equation is given in the Appendix. Using the following equation:—

$$-200 \ln\left(\frac{ET}{T}\right) = 40 \exp(0.1 \sqrt{v}) + \sqrt{v} - 0.3\ RH$$

where ET = effective temperature (°F)
T = dry bulb temperature (°F)
v = wind speed (ms^{-1})
RH = relative humidity (%)

the diurnal variations and the monthly means of effective temperature can be calculated.

OPTIMUM AND HEAT DISCOMFORT CRITERIA

The effective temperature values for the optimum and heat discomfort scale are defined on the basis of the climatological mean of hourly values of the dry bulb temperature, relative humidity and wind speed for the year 1981. The average values of the 0700,0800 and 0900 hrs of observation time gave an indication of the optimum condition whereas the average values of the 0900, 1000 and 1100 hrs of observation gave a guide to the heat discomfort. For the optimum condition the average value of the dry bulb temperature was 24.5°C., relative humidity 94% and under calm condition the effective temperature was calculated as 22.1°C. Similarly, for the heat discomfort the average dry bulb temperature was 27.6°C, relative humidity 82%, hence the effective temperature 24.3°C. Correcting the figures to the nearest 0.5 the optimum condition is characterised by an effective temperature of 22.0°C and the heat discomfort 24.5°C. The actual values could have been lower with some wind blowing.

RESULTS AND DISCUSSION

For a fixed dry bulb temperature and relative humidity, wind speed reduces the effective temperature, thereby inducing comfortable effect. However, there is a limit to reduction of effective temperature due to wind (Figure 1). The graph in Figure 1 shows the effective temperature at varying wind speed during the time of maximum heating at 1400 hrs when the dry bulb temperature was 31°C and relative humidity 69%. A wind speed of 5 ms^{-1} or more is necessary to overcome heat discomfort at 1400 hrs. Further increase in wind speed up to 10 ms^{-1} do not induce optimum comfort. Besides, wind speed greater than 6 ms^{-1} would scatter loose papers and deter concentration.

The monthly means of effective temperatures for Kuching in the year 1981 is shown in Table 1. The lowest effective temperature value of 21.6°C was in January and the highest was in August, 23.4°C. The mean for the year was 22.5°C. In terms of human comfort the months of December and January of 1981 were below the optimum comfort, implying cooler zone whereas the other months have acceptable comfort, which is the zone between the optimum and the heat discomfort. The months of November to March is the North East Monsson period where heavy rain spells are common over Kuching, particularly in December and January. The total rainfall and sunshine hours for various months of 1981 is shown in Table 2. Despite an optimum effective temperature value for the year with

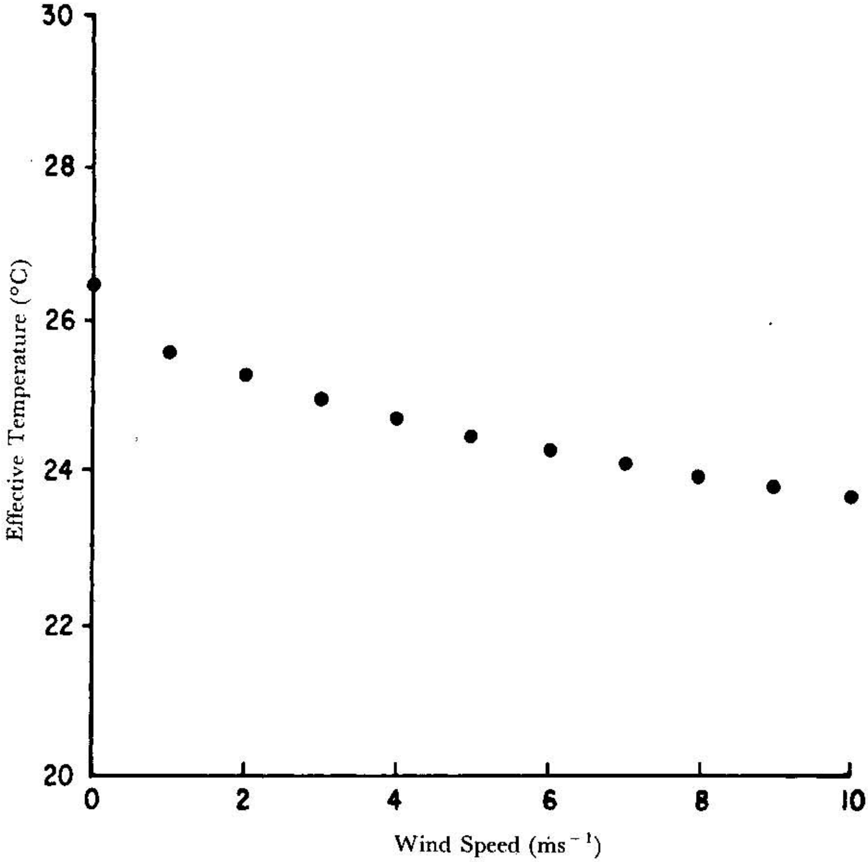

FIGURE 1. Effective Temperature and Anemometer Wind Speed Relationship for a Fixed Temperature and Humidity at Kuching

small departures, the monthly means of effective temperatures do not express clearly the thermal comfort and discomfort situation of the diurnal cycles.

The diurnal variations of effective temperatures present a more realistic feature of the thermal comfort or discomfort at Kuching. One would expect the rainy periods to be cooler, and hence comfortable under indoor conditions, likewise the dry periods to be warmer to create heat discomfort. Assessing the above optimum conditions, only the dry period of May has the highest frequency of heat discomfort for the period of 1968 – 1981 (Table 3), the lowest is January. The annual total indicated the year 1971 has the lowest and 1979 has the highest frequency of heat discomfort. This means that about 8% and 18% of the respective years experienced the heat discomfort.

TABLE 1. Monthly Means of Dry Bulb Temperature (°C), Relative Humidity (%), Surface Scalar Wind Speed (ms^{-1}) and Effective Temperatures (°C) for Kuching 1981

	Jan.	Feb.	Mar.	Apr.	May	Jun	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Dry bulb temp. 24 – hr. mean	25.9	26.0	26.3	26.9	27.3	27.3	26.6	27.8	26.1	26.5	26.0	25.6	26.5
Relative humidity 24 – hr. mean	86	89	88	87	86	85	86	81	87	87	89	90	87
Scalar wind speed	2.6	1.6	1.4	1.5	1.3	0.9	1.2	1.3	1.2	1.3	1.4	1.8	1.5
Effective temp.	21.6	22.2	22.4	22.9	23.3	23.4	22.7	23.4	22.3	22.6	22.2	21.8	22.5

TABLE 2. Monthly Total Rainfall Amount (mm.) Rainfall Days and Daily Mean Sunshine Hours Over Kuching, 1981

	Jan.	Feb.	Mar.	Apr.	May	Jun	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Rainfall amount	168.2	460.9	401.9	304.8	244.4	172.1	209.5	22.2	441.4	224.9	518.8	700.2	3668.5
Rainfall days	17	18	24	18	17	14	21	7	26	23	27	27	239
Sunshine hours	5.8	3.6	3.2	5.5	5.7	6.4	5.7	6.6	3.7	4.8	4.3	2.9	4.9

TABLE 3. Heat Discomfort Freguency (hrs) for Kuching

Year	Jan.	Feb.	Mar.	Apr.	May	Jun	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1968	0	1	32	79	156	152	108	135	123	81	52	48	967
1969	19	4	36	190	182	174	157	86	118	70	48	28	1031
1970	10	22	83	121	177	159	132	114	102	79	86	56	1121
1971	5	13	20	78	169	106	113	44	75	77	12	28	740
1972	1	6	8	58	149	157	215	126	107	94	95	96	1112
1973	17	14	155	112	140	132	146	91	73	83	55	27	985
1974	1	20	10	118	01	97	78	152	58	90	72	40	837
1975	39	28	103	147	163	155	84	161	79	112	58	56	1184
1976	0	20	45	121	208	132	138	27	159	97	87	55	1201
1977	14	4	9	115	159	162	156	159	185	121	92	39	1228
1978	20	15	109	179	208	221	153	197	156	163	80	66	1567
1979	18	64	124	176	255	166	187	204	107	157	92	40	1590
1980	51	26	99	143	245	179	178	141	153	148	112	69	1544
1981	19	54	61	154	202	248	160	249	111	145	116	41	1560

Appendix:

DERIVATION OF EFFECTIVE TEMPERATURE (ET)

In a moderate condition air movement gives a cooler effect. A warm dry air feels rather comfortable than a moist warm air. This suggests that the driving element for coolness or warmth is the dry bulb temperature (T), and the simple relations of ET, T, wind speed (v) and relative humidity (RH) can be expressed as:

$$ET \propto T \exp(-v) \quad (1)$$

$$ET \propto T \exp(+RH) \quad (2)$$

A note by Stephenson and Mcleod (1965) pointed out that Webb (1959) has shown that comfort correlates with the square root of wind speed for Singapore. The work of Adamenko and Khairullin (1972) obtained the dependence of facial skin temperature on the square root of the wind speed. As such the proportionality (1) is now written as

$$ET \propto T \exp(-\sqrt{v}) \quad (3)$$

For climatological study of effective temperature the wind speed were measured by the anemometer of height H above the ground. It is necessary, therefore, to convert the anemometer wind speed (w_s) to the value the same height of the thermometer in the Stevenson screen (height 125 cm). This conversion assumes the logarithmic wind profile given by the following equation:

$$U_H = \frac{U*}{k} \ln \left(\frac{z_H}{z_o}\right) \qquad (4)$$

where U_H is the anemometer wind speed (w_s), $U*$ is the friction velocity, k is the von Karmans constant equals to 0.4; z_H is the anemometer height and z_o is the roughness length of the ground surface. For short grass z_o is taken as 2.0 cm.

The highest anemometer is that of the Headquarters of the Malaysian Meteorological Service (HQPJ) at 29.0 meters and the lowest in Miri at a height of 12.0 meters. A wind speed conversion factor gives,

$$v = 0.5681\ w_s \text{ for HQPJ}$$

$$v = 0.6464\ w_s \text{ for Miri}$$

On average, the whole of Malaysian stations assume $v = 0.6672\ w_s$.

A combination of T, v, RH for evaluating ET assumes the following relationship,

$$\frac{ET}{T} \propto \exp\left(-\sqrt{v} + RH\right) \qquad (5)$$

such that $-\ln\left(\frac{ET}{T}\right) = k_1 \sqrt{v} - k_2 RH + \delta \qquad (6)$

with k_1, k_2 constants and δ the corrector term.
Units: ET, T in °F, v, w_s in ms^{-1}, RH in %.
It was found that δ is a function of v, such that

$$\delta = k_3 \exp\left(0.1 \sqrt{v}\right) \qquad (7)$$

Parameterising the observed values of T, v, RH with ET and with the help of the ASHVE ET nomogram a staole numerical model of ET is derived. The model takes the form of an equation written as

$$-200 \ln\left(\frac{ET}{T}\right) = \sqrt{v} - k_2 RH + k_3 \exp\left(0.1 \sqrt{v}\right) \qquad (8)$$

where $v = 0.6\ w_s$, $k_2 = 0.3$ and $k_3 = 40.0$

A comparison of ET obtained by the model (Malaysian) and that of the ASHVE nomogram introduces a difference in ET values. This is explained by the constant k_2 in which the nomogram seems to take $k_2 = 0.4$. Perhaps this discrepancy is due to the different physiological sensation of comfort.

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