Pilot Study on Occupants’ Thermal Sensation at Different Ambient Temperature in Postgraduate Office with Cooling Mode in University Campus

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With rapid urbanization, massive amount of energy is required to compensate the electricity usage thus calls for a need to Malaysian government issuing standard MS1525:2014 for temperature settings in office buildings to meet energy efficiency goal. In co-sharing spaces, personal thermal comfort is often not met due to the different thermal sensation at different location inside office rooms. This study was conducted at four postgraduate office spaces with cooling mode in university campus located at Kuala Lumpur to evaluate the occupant’s thermal sensation. We used different set-point temperature of air conditioning ranging from 18.0°C to 28.6°C. The indoor thermal variables such as air temperature, globe temperature, relative humidity, and air velocity are measured at each respondent’s workspace and 200 responses were recorded from ten subjects. The mean value of thermal sensations votes is -0.4 and were within comfort range. 76% of responses voted ‘neutral’ humidity sensation as occupants have adapted to humid condition in Malaysia. The comfort operative temperature found in this study is 24.9°C which indicates that the minimum recommended temperature for energy conservation did not deprive occupants from comfort.

Keywords:
Thermal comfort; office rooms; set-point temperature

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1. Introduction

Heating, ventilation and air-conditioning (HVAC) system consumes majority of energy in building of approximately 40% [1]. As urbanization are rapidly arising, thermal properties of land are
tempered causing alteration in urban environmental system which leads to Urban Heat Island (UHI) phenomenon [2,3]. The heated environment can cause great discomfort to humans thus buildings with competent thermal system were built to restore comfort of occupants thermally [4]. A review study shows that there is 0.5 - 8.5% increase in electricity demand for every one-degree temperature rise which is equivalent to 21 (±10.4) Watts per person [5]. A study in an office building in the Philippines discovered 1.4% of cooling energy costs were saved when raising the temperature setting from 22 °C to 24 °C [6] while another study estimated 29% of cooling energy savings when set-point temperature was increased by 2.8 °C [7]. Consequently, the range of indoor parameters are regulated by standards to guide how cooling energy is used in buildings.

Retaining comfort is paramount for the well-being of humans and improved productivity. Standards have been set to specify acceptable range of thermal parameters in indoor environments and although standards are met, not all occupants are thermally satisfied due to different preferences and other potential factors which may not be managed by standards [8]. Studies on thermal comfort are widely done in Europe and United States making the thermal comfort standards from those regions prominent in thermal comfort studies [9-11]. A report done by State of the Tropics in 2014 claimed that 50% of the world’s population will soon live in the tropical region by the year 2050 [12] which simultaneously sees the growing number of thermal comfort studies in predominantly hot and humid countries [5-7,13-15] though thermal comfort studies in the tropics is still considered not plenty [16]. Standards for non-residential buildings in hot and humid countries such as Malaysia [17] and Singapore [18] recommended that operative temperature indoors to be within 24°C to 26°C whilst Indonesia [19] recommends 24°C to 27°C. Study done by Damiati et al., [13] in office buildings found that 80% acceptable operative temperature in cooling mode in Kuala Lumpur and Shah Alam, Malaysia is within 24.5°C to 30°C while mixed mode ventilation in Bandung, Indonesia ranges between 26°C and 28°C which is higher than the recommended standards. Han et al., [20] conducted study in hot and humid climate in central southern China discovered operative temperature of 22.0°C to 25.9°C were considered acceptable by 90% occupants. In a hot summer cold winter climate in Changsha, China, upper limit of operative temperature of 29.4°C met 80% satisfaction of occupants [21]. These studies were done in occupant-controlled conditions where higher satisfactory rate is to be the expected outcome. Studies done in environmentally controlled conditions were typically conducted in climatic chambers [22,23] where there was little adaptation of actual office conditions. A Kuala Lumpur study in 2017 considered the different thermostat temperatures in finding occupants’ thermal satisfaction and observed the ambient temperature at thermostat settings at 20°C, 24°C and 28°C. The study found that at 20°C set-point, ambient temperature was recorded at an average of 24.6°C whilst at 24°C and 28°C set-point, ambient temperature was 25.6°C and 27.5°C respectively. The disparity of set-point and ambient temperature was because of the wide temperature distribution of the location and possible incompetent cooling system of air conditioners. On that account, this study aims to obtain thermal sensation of occupants at controlled ambient temperatures where the cooling system is competent.

2. Methodology
2.1 Description of Study Area

This research takes place from April to September 2019 at a university campus in Kuala Lumpur (3°10'21.3168"N, 101°43'9.3036"E) located in the west peninsular of Malaysia near the equatorial region with tropical rainforest climate. In average, Kuala Lumpur is subjected to maximum temperature of 33°C and 23°C minimum with annual humidity at 80% on average [17]. Four open
plan offices in two investigated buildings (A and B) were selected as study location (See Figure 1). All offices are equipped with one or more ceiling mounted split-type air conditioners with good cooling capability and functional windows. Table 1 shows the descriptions of study locations.

| Building | Office Code | IF/TF | Orientation | Area ($m^2$) | $N_R$ | $N_S$ |
|----------|-------------|-------|-------------|-------------|-------|-------|
| A        | KL1         | 10/10 | East        | 22.9        | 3     | 40    |
|          | KL2         | 4/10  | East        | 37.0        | 2     | 32    |
|          | KL3         | 5/10  | North       | 56.4        | 3     | 48    |
| B        | KL4         | 2/2   | Southwest   | 51.1        | 5     | 80    |

Note: IF; Investigated Floor, TF; Total Floor, $N_R$; Number of Respondents, $N_S$; Number of samples

![Image of offices](image)

**Fig. 1.** Investigated offices

### 2.2 Thermal Measurements

Indoor environmental parameters measured in this study are air velocity ($v_a$), air temperature ($T_a$), globe temperature ($T_g$) and relative humidity ($R_H$). Air temperature, $T_a$ was measured using HHA-3151 and TMC1-HD sensors, A 40 mm black sphere is fixed to another TMC1-HD sensor to measure globe temperature. HOBO data logger internal sensor was used to measure $R_H$ while Kanomax 6501-0G with hot wire anemometer probe 6542-2G measures $v_a$ (See Figure 2). Outdoor temperature ($T_o$) and outdoor humidity ($R_{Ho}$) were taken from weather station located at rooftop of ten-storey Building A. All instruments were calibrated before conducting field measurements. Indoor measurements were recorded at 10 seconds intervals over 10-20 minutes sampling time after instruments were stable. Instruments were placed at 1.1m height near occupants’ work cubicle within 0.3m radius [24] as shown in Figure 3 and 4. Similar setup was conducted in Malaysian offices for thermal comfort field studies by Damiati *et al.* [13] and Mustapa *et al.*, [25]. Table 2 shows the information of instruments used in this study. Field measurement was conducted from 9:00AM to 12:00PM for morning session and 1:00PM to 6:00PM for afternoon session when offices were occupied.
Fig. 2. Equipment setup

Fig. 3. Field measurement setup. Red dotted circle shows the equipment setup during field measurement

Fig. 4. Field measurement setup in KL3 (left) and KL4 (right)

Table 2
Specifications of instruments used for indoor field measurement

| Device          | Sensor                      | Parameter Measured   | Range              | Accuracy                                      |
|-----------------|-----------------------------|----------------------|--------------------|-----------------------------------------------|
| TnD TR-77Ui     | HHA-3151                    | Air Temperature      | -30 to 80°C        | ±0.3°C (10 to 40°C)                           |
|                 |                             |                      |                    | ±0.5°C (at all other temperatures)            |
|                 |                             | Relative Humidity    | 0 to 99% RH        | ±2.5% RH (at 25°C and 10 to 85% RH)           |
|                 |                             |                      |                    | ±4% RH (at 25°C and 0 to 10% RH or 85 to 99% RH) |
| HOBO Data Logger| Internal sensor             | Relative Humidity    | 5 to 95% RH        | ±2.5% (10 to 90% RH)                          |
|                 | TMC1-HD sensors             | Air Temperature      | -40° to 100°C      | ±0.25°C (0 to 50°C)                           |
|                 | TMC1-HD sensors + 40mm black sphere | Globe Temperature | -40° to 100°C      | ±0.25°C (0 to 50°C)                           |
| Kanomax 6501-0G | Needle Probe 6542-2G       | Air Velocity         | 0.01 to 50 m/s     | ±2% or 0.015 m/s                              |
2.3 Subjects and Thermal Comfort Survey

Ten postgraduate students between 22 and 30 years old volunteered as subjects in this study consisting of eight females and five males. All subjects have signed consent forms in compliance to Malaysian Personal Data Protection Act 2010. Subjects’ information was obtained in the first part of questionnaire. Subjects underwent multiple measurement sessions in the morning and afternoon where each session, as depicted in Figure 5 lasted up to one-hour duration depending on air temperature stability in the room. 200 responses were collected from all subjects.

Figure 5. Field measurement procedure

Questionnaire was split to two parts where the first part includes subjects’ demographic and anthropometric information which was filled only once while part two were answered after each field measurement. Part two of questionnaire were distributed online via Whatsapp or email using Google Form after researcher confirmed the temperature indoors has stabilized. The ‘right here right now’ responses were then recorded. Part two consists of health condition, thermal sensation, preference, activity level and clothing insulation. A revised four-point health assessment scale is adopted from previous study [15] to assure that the response was not influenced by subjects’ poor health. The frequently used seven-point thermal sensation vote (TSV) evaluation was taken from The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and modified (mTSV) based on preceding study by Khalid et al., [15] for the reason that warm-hot and cold-cool possibly gives parallel meaning in Malay language. Thermal sensation, preference, air movement vote and overall comfort scale is shown in Table 3.

Table 3
Thermal comfort survey scale

| Scale | Thermal Sensation Vote (TSV) | Thermal Preference (TP) | Humidity Sensation (HS) | Humidity Preference (HP) | Air Movement Vote (AMV) | Overall Comfort (OC) |
|-------|-----------------------------|-------------------------|------------------------|------------------------|------------------------|---------------------|
| -3    | Very cold                   | Much cooler             | Very dry               | Much drier             | No movement            | Very uncomfortable  |
| -2    | Cold                        | A bit cooler            | Dry                    | A bit drier            | Low                    | Moderately comfortable |
| -1    | Slightly cold               | No change               | Slightly dry           | No change              | High                   | Slightly uncomfortable |
| 0     | Neutral                     | A bit warmer            | Slightly humid         | A bit humid            | Neither high nor low   | Slightly comfortable |
| 1     | Slightly hot                | Much warmer             | Humid                  | More humid             | High                   | Very comfortable    |
| 2     | Hot                         | Very hot                | Very humid             |                        |                        |                     |
| 3     |                               |                         |                        |                        | High                   |                     |
| 4     |                               |                         |                        |                        | Neither high nor low   |                     |
| 5     |                               |                         |                        |                        | High                   |                     |
| 6     |                               |                         |                        |                        | Neither high nor low   |                     |
|       |                               |                         |                        |                        | High                   |                     |
Personal factors of activity level and subjects’ clothing were included in the later part two of the survey to estimate the metabolic rate \((\text{met})\) and clothing insulation \((\text{clo})\) based on ASHRAE Standard 55 2017 [9].

3. Results

3.1 Thermal Environments and Personal Parameters

The personal parameters and thermal environment data were recorded during field measurement at occupants’ work spaces and the mean values were obtained as shown in Table 4. \(T_a\) and \(T_g\) has similar mean values while \(RH\) fluctuates with higher deviation compared to other thermal indices. KL1 recorded highest mean \(T_a\) of 24.6\(^\circ\)C compared to other study location. Based on observation, the non-airtight glass doors in KL1 could contribute to external heat coming from the corridor although the performance factor of air conditioner cannot be ruled out. Mean values of \(V_a\) ranges from 0.14 to 0.29 \(\text{m/s}\) which is acceptable with almost unnoticeable sensation according to Malaysian Standard 2014 [17]. Mean values of clothing insulation and metabolic rate were 0.53\(\text{clo}\) and 1.1\(\text{met}\) respectively which is equivalent to shirt and pants ensemble with sedentary activity.

Additionally, we explored the relation between air temperature, \(T_a\) and setting temperature of air conditioner, \(T_s\) and noticed that they were significant and highly correlated as portrayed in Table 5. The relation between thermal indexes was also analysed due to multiple thermal indices present in this study. \(T_a\) was found to have high correlation with \(T_g\), \(T_{mrt}\) and \(T_{op}\) as depicted in Table 6 indicating that any of the thermal index can be used in analysis. Ultimately, \(T_{op}\) was selected in accordance to previous studies [13,15,25].

### Table 4

| Offices | Item  | \(T_a\) (°C) | \(T_g\) (°C) | \(T_{mrt}\) (°C) | \(T_{op}\) (°C) | \(R_H\) (%) | \(R_{H_o}\) (%) | \(V_a\) (m/s) | \(I_{cl}\) (clo) | \(M\) (met) |
|---------|-------|-------------|-------------|-----------------|-----------------|-------------|-------------|--------------|---------------|------------|
| KL1     | Mean  | 24.6        | 24.8        | 25.2            | 24.8            | 30.3        | 64.8        | 67.5         | 0.29          | 0.59       | 1.0        |
| (n=40)  | S.D.  | 2.3         | 2.1         | 1.8             | 2.0             | 2.5         | 6.5         | 13.4         | 0.17          | 0.19       | 0.2        |
|         | Max.  | 28.6        | 28.3        | 27.9            | 28.3            | 33.1        | 80.1        | 95.9         | 0.63          | 0.94       | 1.7        |
|         | Min.  | 20.6        | 21.0        | 21.7            | 21.1            | 24.0        | 52.5        | 49.1         | 0.02          | 0.30       | 0.2        |
| KL2     | Mean  | 23.8        | 24.2        | 24.7            | 24.2            | 31.2        | 56.8        | 68.6         | 0.17          | 0.60       | 1.1        |
| (n=32)  | S.D.  | 2.3         | 2.0         | 2.1             | 2.1             | 1.3         | 3.1         | 7.3          | 0.06          | 0.11       | 0.1        |
|         | Max.  | 26.8        | 26.9        | 28.0            | 28.0            | 33.3        | 62.0        | 83.9         | 0.40          | 0.96       | 1.7        |
|         | Min.  | 18.0        | 18.7        | 19.6            | 18.6            | 29.2        | 51.6        | 56.2         | 0.09          | 0.30       | 0.8        |
| KL3     | Mean  | 22.9        | 23.3        | 23.7            | 23.2            | 30.4        | 58.1        | 70.2         | 0.14          | 0.58       | 1.0        |
| (n=48)  | S.D.  | 2.4         | 2.3         | 2.2             | 2.3             | 1.2         | 6.7         | 7.4          | 0.08          | 0.10       | 0.2        |
|         | Max.  | 27.0        | 27.1        | 27.3            | 27.1            | 32.7        | 70.9        | 79.0         | 0.27          | 0.79       | 1.7        |
|         | Min.  | 18.9        | 19.2        | 19.7            | 19.3            | 28.3        | 49.1        | 55.8         | 0.02          | 0.35       | 0.7        |
| KL4     | Mean  | 23.8        | 24.1        | 24.7            | 24.2            | 30.0        | 65.0        | 72.5         | 0.24          | 0.44       | 1.1        |
| (n=80)  | S.D.  | 2.2         | 2.1         | 2.2             | 2.1             | 2.4         | 6.8         | 11.6         | 0.12          | 0.15       | 0.2        |
|         | Max.  | 28.0        | 28.0        | 28.9            | 28.1            | 34.3        | 78.6        | 100.0        | 0.73          | 0.98       | 1.7        |
|         | Min.  | 18.9        | 19.7        | 18.8            | 19.7            | 23.2        | 51.3        | 45.8         | 0.05          | 0.19       | 1.0        |

Note: \(T_a\): Indoor air temperature (°C), \(T_g\): Globe temperature (°C), \(T_{mrt}\): Mean radiant temperature (°C), \(T_{op}\): Operative temperature (°C), \(T_s\): Outdoor temperature (°C), \(R_H\): Relative Humidity (%), \(R_{H_o}\): Outdoor relative humidity, \(V_a\): Indoor air velocity (m/s), \(I_{cl}\): Clothing insulation, \(M\): Metabolic rate, n: Number of samples, S.D.: Standard deviation, Max.: Maximum, Min.: Minimum
### Table 5
Correlation of $T_a$ and $T_s$

| Equation                           | KL1 (n=40) | KL2 (n=32) | KL3 (n=48) | KL4 (n=80) |
|------------------------------------|------------|------------|------------|------------|
| $T_a = 0.557T_s + 11.11$          | 0.557      | 0.537      | 0.577      | 0.837      |
| $T_s = 0.537T_a + 11.32$          | 0.537      | 0.577      | 10.24      | 3.29       |
| $T_a = 0.577T_s + 10.24$          | 0.577      | 10.24      |            |            |
| $T_s = 0.837T_a + 3.29$           | 0.837      |            |            |            |
| $r$                                | 0.904      | 0.928      | 0.945      | 0.932      |

Note: $T_a$: Indoor air temperature (°C), $T_s$: Setting temperature (°C), n: Number of samples, r: Correlation coefficient. Note: all correlation coefficients are significant (p<0.001).

### Table 6
Correlation of $T_a$ with $T_g$, $T_{op}$ and $T_{mrt}$

| Items | Equation | $T_g$: $T_a$ | $T_{op}$: $T_a$ | Equation | $T_g$: $T_a$ |
|-------|----------|-------------|----------------|----------|-------------|
| $T_g$: Globe temperature (°C), $T_{op}$: Operative temperature (°C), $T_{mrt}$: Mean radiant temperature (°C), r: Correlation coefficient, N: Number of samples. Note: all correlation coefficients are significant (p<0.001). |
| $T_g = 2.74 + 0.90T_a$ | $T_{op} = 2.77 + 0.90T_a$ | $T_g = 2.74 + 0.90T_a$ | $r (N=200)$ | 0.969 | 0.972 | 0.969 |

### 3.2 Distribution of Subjective Votes

Based on the mean values of $mTSV$ in all study locations (Table 7), occupants were generally in the comfort range ($-1 \leq mTSV \leq 1$) when exposed to different air temperatures. Approximately 76% of responses were within the comfort range, as displayed in Figure 6. Moreover, the thermal sensation votes were leaning towards cooler sensation with 17% responses voted (-2) and (-3) compared to only 7% voted (+2) and no votes for (+3). All locations recorded cooler thermal sensation however KL2 has a preference for slightly warmer conditions despite having ‘cooler’ thermal sensation votes in average. More than half of the responses (55%) has ‘neutral’ sensations towards humidity (Figure 7). This may be due to the small effect of humidity has on comfort temperature [22] in addition to residing in a hot and humid country thus the occupants could have been adapted to the humid surroundings.

### Table 7
Mean values of subjective votes

| Office | Item | $mTSV$ | $TP$ | $HS$ | $HP$ |
|--------|------|--------|------|------|------|
| KL1 (n=40) | Mean | -0.6 | 0.4 | -0.4 | 0.3 |
| KL2 (n=32) | Mean | -0.3 | -0.2 | 0.0 | 0.5 |
| KL3 (n=48) | Mean | -0.6 | 0.2 | 0.4 | -0.2 |
| KL4 (n=80) | Mean | -0.3 | 0.0 | 0.0 | 0.2 |

Note: $mTSV$: Modified Thermal Sensation Vote, $TP$: Thermal Preference, $HS$: Humidity Sensation, $HP$: Humidity Preference, $OC$: Overall Comfort, n: Number of samples
3.3 Comfort Temperature
3.3.1 Regression method

Determining comfort temperature, $T_c$, via regression involves finding the neutral temperature by examining the relationship between $mTSV$ and $T_{op}$ as shown in Figure 8 and can be represented as below

$$mTSV = 0.34T_{op} - 8.71 \quad (N = 200, R^2 = 0.414, S.E. = 0.029, p < 0.001)$$ \quad (1)

where $R^2$ is the coefficient of determination, $N$ is the number of samples, $S.E.$ is the standard error of regression coefficient, and $p$ is the significance level of regression coefficient. Referring to Eq. (1), comfort temperature when $mTSV=0$ or ‘neutral’ is 25.6°C. Moreover, 2.9°C is contributed for every +1 scale of unit change in $mTSV$ based on the slope of regression lines (0.34units/°C). Due to the 2.9°C scale-based change, regression method is unreliable and in line with previous studies [15,25]. Hence, Griffiths method is adopted to find comfort temperature
3.3.2 Griffiths method

On account of low and unreliable slope of regression line, comfort temperature was estimated using Griffiths method by calculating $T_c$ from each response using the following equation

$$T_c = T + \frac{(0 + mTSV)}{\alpha}$$

(2)

where $T_c$ is comfort temperature, $T$ is any of the thermal index ($T_a, T_g, T_{mrt}, T_{op}$), $mTSV$ is the modified thermal sensation vote and $\alpha$ is the Griffiths constant. In this study, $\alpha = 0.50$ is used as previously practised by Damiati et al., [13], Mustapa et al., [25] and Khalid et al., [15] for comfort temperature in hot and humid countries. Comfort temperature found in this study is 24.9°C as shown in Table 8 and 9.

| Table 8 | Comfort temperature using Griffiths method |
|---------|------------------------------------------|
| Item    | $T_{ca}$ ($^\circ$C) | $T_{cg}$ ($^\circ$C) | $T_{cmrt}$ ($^\circ$C) | $T_{cop}$ ($^\circ$C) |
| Mean    | 24.6 | 24.9 | 25.4 | 24.9 |
| S.D.    | 2.0 | 2.0 | 2.1 | 1.9 |

Note: $T_{ca}$: Comfort air temperature ($^\circ$C), $T_{cg}$: Comfort globe temperature ($^\circ$C), $T_{cmrt}$: Comfort mean radiant temperature ($^\circ$C), $T_{cop}$: Comfort operative temperature ($^\circ$C)

| Table 9 | Comfort temperature comparison with mean operative temperature |
|---------|---------------------------------------------------------------|
| Item    | $T_{cop}$ ($^\circ$C) | $T_{mop}$ ($^\circ$C) |
| Mean    | 24.9 | 24.8 | 24.2 |
| S.D.    | 1.9 | 1.9 | 2.1 |

Note: $T_{cop}$: Comfort operative temperature ($^\circ$C), $T_{mop}$: mean operative temperature ($^\circ$C), $mTSV$: Modified thermal sensation vote, OC: Overall comfort
We also compared our results with previous study that adopted Griffiths method to estimate comfort temperature in cooling mode ventilation. The $T_c$ in this study is much lower than previous studies as depicted in Table 10. In comparison to previous studies, occupants in this study experienced varying thermal conditions and felt comfortable at lower temperature.

Table 10  
Comparison of comfort temperature from previous studies adopting Griffiths method  

| Reference       | Location                        | N   | $T_c$ (°C) | Mean | S.D. |
|-----------------|---------------------------------|-----|------------|------|------|
| This study      | Kuala Lumpur, Malaysia          | 200 | 24.9       | 24.9 | 1.9  |
| Mustapa et al., [25] | Fukuoka, Japan (Summer)        | 222 | 26.6       | 26.6 | 1.6  |
| Damiati et al., [13] | Kuala Lumpur and Shah Alam, Malaysia | 1114 | 25.6       | 25.6 | 2.2  |
|                 | Bandung, Indonesia              | 91  | 26.3       | 26.3 | 2.3  |
|                 | Singapore                       | 14  | 26.4       | 26.4 | 2.1  |
|                 | Japan (Summer)                  | 418 | 25.8       | 25.8 | 1.4  |

Note; $T_{cap}$: Comfort temperature (°C), N: Number of samples, S.D.: Standard deviation

4. Conclusions

This study presented the thermal sensation of occupants in postgraduate office space with cooling mode (CL) in Kuala Lumpur, Malaysia at different set-point air temperature ranging from 18.0°C o 28.6°C. During field measurement, thermal environments and personal parameters were recorded objectively while thermal sensations were subjectively taken via questionnaire yielding 200 responses. Occupants mainly feels comfortable with 76% of the votes falls within the comfort range with average thermal sensation vote (TSV) of -0.4. Adaptation of occupants in humid country could be the contributing factor to the major portion of responses (55%) voted ‘neutral’ humidity sensation and prefers no change. Comfort temperature estimated by regression analysis was found to be 25.6°C while Griffiths method approximated 24.9°C, close to mean values of operative temperature. The comfort temperature found in this study shows that the current minimum recommendation set by the Malaysian government in non-residential buildings to conserve energy does not sacrifice comfort of occupants.

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