Report on thermal comfort study in Bandung, Indonesia

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Abstract
A thermal comfort study was conducted at the School of Architecture, Institute of Technology Bandung (ITB) at Bandung - Indonesia, on the 8th October 2005. Bandung is the capital of West Java province and is located at the 7° South Latitude. Situated at about 700m above sea level, this city possesses a warm humid tropical climate with an average minimum of monthly outdoor temperature of 18°C and an average maximum of 28°C. This study was carried out in a small lecture room, which was performed look like a 'thermal chamber'. A number of instruments were employed to measure the indoor climatic parameters of the room, whilst, twenty participants of ten males and ten females of college-age students participated in this study voluntarily to give their thermal responses. This paper discusses the whole study and provides some comparison to Karyono comfort study in Jakarta few years ago. It also provides some analyses to the building energy conservation and the applicability of the Adaptive model in Indonesia.

Keywords: actual mean vote (AMV), Bandung, comfort range, neutral temperature.

1. Introduction

A recent thermal comfort study has been conducted at the Department of Architecture, Institute of Technology Bandung (ITB) at Bandung - Indonesia, on the 8th October 2005. Bandung is the capital of West Java province and is located at the 7° South Latitude. Situated at about 700m above sea level, this city possesses a warm humid tropical climate with an average minimum of monthly air temperature of 18°C and an average maximum of 28°C. The range of relative humidity is between 60% and 95%. The average monthly outdoor temperature is about 23°C and is lower than that of Jakarta which is about 28.5°C. One of the aims of this study is to compare neutral temperature and comfort range of Bandung subjects based on this study with that of Jakarta study done by Tri Karyono in 1993 [1].

2. Methodology

This thermal comfort study was carried out in a small lecture room, which was performed look like a ‘thermal chamber’. The room was sealed and protected from any air infiltration from outside the room. In order to have such indoor climatic variations, the room, of 6m x 5.4m x 2.8m in size, was cooled by a split-AC machine before being used for measurements.

Figure 1. Atmosphere of taking measurements

A number of instruments were used to measure the indoor climatic parameters of the room. They were a 15cm-diameter globe thermometer painted black to measure radiant temperature (globe temperature), a digital thermo-hygrometer to measure air temperature and relative humidity, a digital indoor anemometer to measure air velocity, and a B&K thermal comfort meter type 1212 to measure PMV and PPD.

In order to get such a homogeneous environment, the split-AC machine of the room was shut down few minutes before the actual measurements were taken. Twenty participants of ten males and ten females of college-age students entered the room and seated in a rather circular position in which all the instruments were put nearly at the centre of the room. Eight measurements in different climatic conditions were taken by measuring some climatic parameters of the room: globe temperature, air temperature, RH, and air movement. Along with these measurements, subjects’ thermal votes were collected. At the same time PMV and PPD were also recorded by means of B&K thermal comfort meter type 1212. Another two measurements were taken in different rooms at the same building which made them ten measurements for all.

Subjects’ neutral temperature and comfort ranges were calculated in terms of air temperature, globe temperature, operative temperature and standard equivalent temperature (SET). Air and globe temperatures were measured by means of a digital thermo-hygrometer and 15cm-diameter black globe thermometer respectively. The operative temperature is calculated as a function of air temperature (T_a) and radiant temperature (T_r) according to the given formula below.

$T_o = AT_a + (1-A)T_r$

At the presence of air velocity below 0.2 m/s, the value of T_r is the same as T_g (globe temperature) ($T_r = T_g$) [2]. Values of 'A' can be found from Table 1 below as a function of air velocities (V_a), in a meter per second [2].

Table 1. Values of 'A' as a function of air velocities

V_a	<0.2	0.2 to 0.6	0.6 to 1.0
A	0.5	0.6	0.7

From the table, it can be seen that the air velocity below 0.2 m/s will produce A = 0.5. Therefore, since the air velocities were always recorded below 0.2 m/s in all the measurements, the equation is thus can be defined as:

$T_o = 0.5T_a + (1-0.5)T_g$

Or,

$T_o = 0.5T_a + 0.5T_g$

Meanwhile, SET is defined as the temperature of an isothermal environment which has air and mean radiant temperature equal to each other, a relative humidity of 50% and still air, in which a person with a standard level of clothing insulation would have the same heat loss at the same mean skin temperature and the same skin wettedness as he does in the actual environment and clothing insulation under consideration [3]. SET is a function of clothing and activity, as well as the physical variables of environment. The value of SET is directly linked to sensation and not to air temperature [3]. In this work, the value of SET is calculated by means of software of ASHRAE Basic Thermal Comfort Model.

2.2. Physical measurement

Physical data of indoor environment were measured by means of a globe thermometer, an anemometer, and a thermo-hygrometer. Since the split AC machine of the room was shut down before the first measurement was taken in the small room, the room air temperature was increased from time to time. Along with indoor climatic parameter measurements, subjects' thermal responses, based on seven-point scale: cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2) and hot (+3), were collected from all the 20 participants in various thermal conditions.

Eight measurements were taken in this small room and another two measurements were taken from another two different rooms, which were naturally ventilated. All these has brought of 200 subjects' thermal votes. The idea of taking the last two measurements in different rooms was to have more indoor climatic variations since the small room was getting cooler again after the eighth measurement was taken.

3. Data of Thermal Comfort Measurements

Twenty subjects participated in this study consisted of ten males and ten females students of architectural students of ITB. Subjects were between 19 and 24 years with a mean of 20.35 and STD of 2.04

In terms of height, the shortest subject was 150 cm and the tallest was 185 cm with the mean of 163.45 cm and standard deviation (SD) of 8.88 cm. The lightest subject was 40 kg and the heaviest was 75 kg with an average of 54.55 kg and SD of 11.14 kg. The range of subjects' Du Bois area was between 1.33 and 1.98 m^2, with a mean of 1.58 m^2 and SD of 0.19 m^2. Du Bois area is calculated on the basis of an equation: $A_{Du}=0.202W^{0.425}H^{0.725}$ [3].

Although not all the subjects are originated from Bandung, they had been staying in this city for 9.5 years on average. The subject's longest stay was 20 years and the shortest stay was one year, with the SD of 8.36 years. This study does not attempt to analyse subjects' ethnic background in relation to thermal comfort, therefore, there was no data collection of subjects' ethnic backgrounds.

Since subjects were conducting light activities (seating and reading some magazines or chatting), the activity level of all subjects was taken as 1 met (50 kcal/h.m^2 or 58 W/m^2). This is according to the value recommended by the Manual book of Thermal Comfort Meter for the light activities [4] and ISO-7730 [5]. Subjects' were wearing light tropical clothes, such as short and long sleeves thin cotton shirts, t-shirt, long trousers for males and either long trousers or long dresses for females. Five out of ten female subjects were wearing thin scarf, however, this has not been taken into account on the estimation of subjects' clothing values in this studies. On average, subjects' clothing values were estimated to be between 0.6 and 0.7clo.

Indoor air temperatures ranged between 26^{o}C and 29^{o}C T_a, with an average of 27.2^{o}C, and SD 1.03^{o}C. Globe temperatures were measured to be between 25.5 and 30^{o}C, with an average of 28.15^{o}C and SD of 1.56^{o}C. The operative temperatures (T_o, calculated as a combination effect of air and meant radiant temperature) ranged between 25.4 and 30.7^{o}C, with the mean of 28.9^{o}C and SD of 1.54^{o}C. The air humidity ranged between 49% and 68%, with an average of 59.8%, and SD of 6.8%. The air movement were almost still, ranged between 0m/s and 0.05m/s. Subjects mean votes were ranged between – 0.6 and + 1.05 with an average of 0.71 (between neutral dan slightly warm) and SD of 0.59.

3. Analyses and Results

Data of ten-set climatic parameters of the rooms along with 200 subjects' thermal votes were then analysed. Linear regressions of actual mean vote (AMV) against temperatures (T_a, T_g, T_o, SET) were applied to determine subjects' neutral temperature and comfort range. Temperatures were measured in two different forms: air (T_a) and globe (T_g), whilst, operative temperature (T_o) and Standard Effective Temperature (SET) were calculated from a number of measured data by means of ASHRAE Basic Thermal Comfort Model software. On the other hand, PMV and PPD were recorded by means of Thermal Comfort Meter type 1212, however, there will be no further analysed regarding to these matters in this paper.

3.1. Subjects' neutral temperature and comfort range in terms of air temperature (T_a)

A linear regression of AMV on T_a (Fig 2) gives an equation of AMV = $0.2896T_a$ - 7.1667, with a coefficient of correlation (r) of 0.51. This has produced subjects' neutral temperature (T_n) of 24.7°C T_a and comfort range, T_{cr}, (AMV between – 0.5 and + 0.5) as between 23 and 26.5°C T_a.

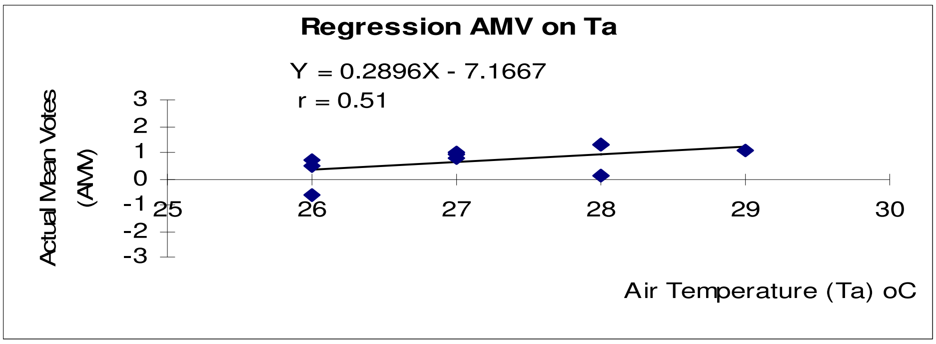

Figure 2. Regression of actual mean vote (AMV) on air temperature (T_a)

3.2. Subjects' neutral temperature and comfort range in terms of globe temperature (T_g)

Figure 3 shows a linear regression of AMV on T_g. This regression gives an equation of AMV = $0.2893T_g$ - 7.4325, with a coefficient of correlation (r) of 0.77. This has produced subjects' neutral temperature (T_n) of 25.7°C T_a, and comfort range, T_{cr}, (AMV between – 0.5 and + 0.5) as between 22.2 and 27.4°C T_g.

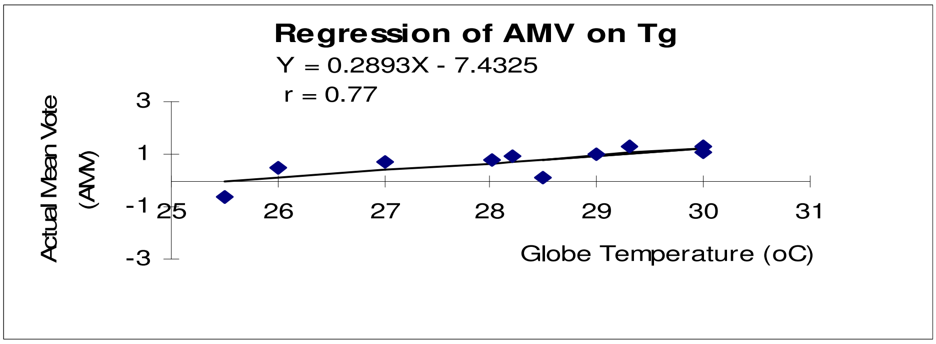

Figure 3. Regression of actual mean vote (AMV) on globe temperature (T_g)

3.3. Subjects' neutral temperature and comfort range in terms of operative temperature (T_o)

Figure 4 shows a linear regression of AMV on T_o. An equation of AMV = 0.3136 T_o - 7.9734 (r = 0.68) was derived from the regression and has produced subjects' neutral temperature (T_n) of 25.4°C T_o, and comfort range, T_{cr}, (AMV between – 0.5 and + 0.5) of between 23.8 and 27°C T_o

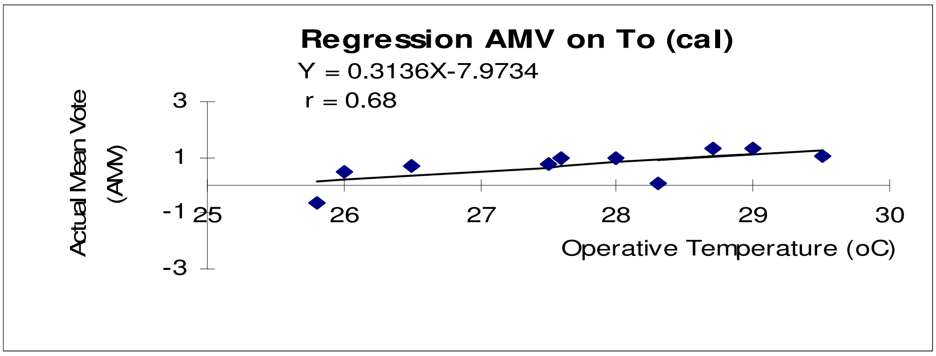

Figure 4. Regression of actual mean vote (AMV) on operative temperature (T_o)

3.4. Subjects' neutral temperature and comfort range in terms of Standard Effective Temperature (SET)

Figure 5 shows a linear regression of AMV on T_{SET}, which gives an equation of AMV = $0.2678T_{SET}$ - 6.9877, with a coefficient of correlation (r) of 0.76. Deriving from this equation, subjects' neutral temperature (T_n) was found to be 26.1°C T_{SET}, and comfort range, T_{cr}, (AMV between – 0.5 and + 0.5) was between 24.2 and 28°C T_{SET}.

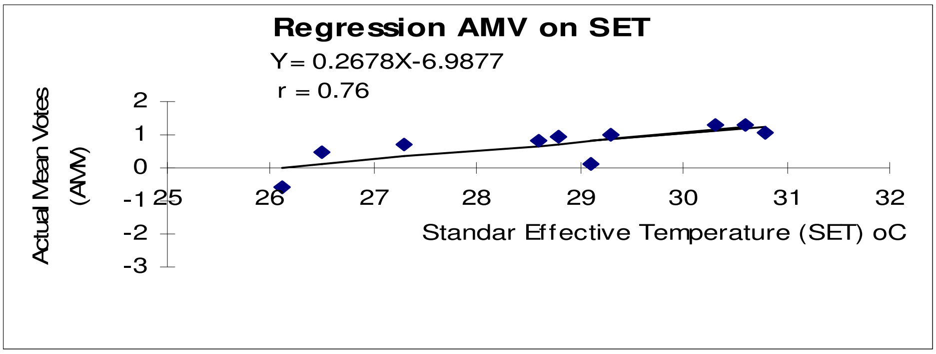

Figure 5. Regression of actual mean vote (AMV) on standard effective temperature (T_{SET})

3.5. Comparison with Jakarta's thermal comfort study

Bandung possesses mean monthly outdoor temperatures of about 23°C, which is lower than that of Jakarta, which possesses about 28°C. One of the aims of this study is to see whether mean monthly outdoor temperatures incorporate with people choice on their thermal environment as defined by the Adaptive model.

Previous thermal comfort study done in Jakarta by Tri Karyono in 1993 [1,6] showed that subjects under 40 years of age (slightly comparable with Bandung college-age subjects) had slightly higher neutral temperatures and comfort ranges than that of Bandung study (Table 2). Jakarta comfort study involving 596 participants of office workers found out subjects' neutral temperature (95% comfortable; mean votes is zero) of 26.4°C and subjects' comfort range (90% comfortable; mean votes between –0.5 and +0.5) of between 24.8 and 27.9°C in terms of air temperature (T_a). In terms of operative temperature (T_o), subjects' neutral temperature was 26.7°C and comfort range was between 25.3°C and 28.5°C. While in terms of equivalent temperature, neutral temperature of subjects was found to be 25.3°C and the comfort range was between 23.8 and 27.1°C. Jakarta is situated on the north coastal island of Java, at 6° south-latitude, while Bandung is located at the highland. The mean monthly temperature of Jakarta is 28.5°C, with monthly minimum average temperature is 23°C and maximum average is 33°C, and is higher than Bandung.

Previous Karyono's comfort study in Jakarta published in a number of journals stated slightly different outcomes to the values attaches on the Table 2 below. This is due to the different assumption on its calculation. The published articles assumed that comfort range was based on 75% subjects' satisfaction, and taking subjects' thermal votes of between –1 and +1 as the range for comfort range calculation. While in Table 2, subjects' comfort range were based on 90% subjects' satisfaction, and taking subjects' comfort votes of between –0.5 and +0.5 as the range for comfort range calculation.

Table 2. Comparison of neutral temperature and comfort range between Jakarta and Bandung studies

NO	TEMPERATURES (°C)	JAKARTA (under 40 yrs-old workers)			BANDUNG (college-age students)			DIFFERENCE	
		Outdoor Monthly average (°C)	T_n (°C) AMV =0	T_{cr} (°C) AMV between –0.5 and +0.5	Outdoor Monthly average (°C)	T_n (°C) AMV =0	T_{cr} (°C) AMV between –0.5 and +0.5	T_n (°C)	T_{cr} (°C)
1	Air Temperature (T_a)	28.5	26.8	24.9-28.0	23	24.7	23.0-26.5	- 2.1	-1.9 to -1.5
2	Globe Temperature (T_g)		n.a.	n.a.		25.7	22.2-27.4		
3	Operative Temperature (T_o)		27.1	25.2-28.4		25.4	23.8-27.0	-1.7	-1.4
4	Equivalent Temperature (T_e)		25.8	23.6-27.3		n.a.	n.a.		
5	Standard Effective Temperature (SET		n.a.	n.a.		26.1	24.2-28		

From Table 2, it can be seen that based on the data available, the difference of subjects' neutral temperature was about 2.1°C, and the difference of comfort range was about 1.9 to 1.5°C in terms of air temperature. In terms of operative temperature the difference was about 1.7°C on its neutral temperature, and was about 1.4°C on its comfort range. On average, Bandung subjects seemed to be more comfortable in lower temperatures than the Jakarta subjects. Result from this study shows that subjects' neutral temperature of Bandung was lower than that of subject's neutral temperature based on Jakarta's thermal comfort study done by Tri Karyono in 1993 [1,6]. Further analyses might be reached the conclusion on how far the adaptive model of thermal comfort [7,8,9,10,11] – which defined thermal comfort as function of mean monthly outdoor temperature - can be working in this kind of climate

4. Conclusion

Results from the analyses shows that subjects' neutral temperature was found to be 24.7°C in terms of air temperature (T_a) or 25.7°C in terms of globe temperature (T_g) 25.4°C in terms of operative temperature (T_o) or 26.1°C in terms of standard effective temperature (T_{SET}).

Subjects' comfort range (90% comfortable level) was found to be between 23 and 26.5°C in terms of air temperature (T_a), or between 22.2 and 27.4°C in terms of globe temperature (T_g), or between 23.9 and 27°C in terms of operative temperature (T_o), or between 24.2 and 28°C in terms of standard effective temperature (T_{SET}). This study shows that with lower monthly average outdoor temperatures, Bandung subjects were likely to be more comfortable in the presence of lower indoor temperatures than the Jakarta subjects with higher monthly average outdoor temperatures. This study has shown that subjects' comfort temperatures were in line with mean monthly outdoor temperatures as stated by Humphreys and Nicol [7,8,9] and Auliciem [10,11] in their Adaptive model equations.

Result from study also shows that subjects' neutral temperature (24.7°C T_a) is slightly higher that the mean monthly outdoor temperature (23°C T_a), while in the case of Jakarta, the neutral temperature (26.8°C T_a) was slightly lower than its mean outdoor temperature (28.5°C T_a). This shows that there must be a limit of upper and lower temperatures in which people may still be felt comfortable, regardless to the outdoor temperatures they may experience with.

The mean and the average maximum monthly outdoor temperatures of Bandung (23 to 28°C T_a) were just about the subjects' comfort ranges in any terms of temperature (23-26.5°C T_a, or 22.2- 27.4°C T_g, or 23.9-27°C T_o, or 24.2-28°C T_{SET}). In terms of energy conservation, any building in Bandung would not require either cooling or heating throughout the year if it were designed properly by considering the local climate. Since the mean minimum outdoor temperature is just about 18°C, people may adjust their thermal comfort requirements by wearing thicker clothes rather than installing heating equipments when the indoor temperatures fall below the subjects' comfort range.

5. Acknowledgement

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6. References

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