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Thermal comfort study of university students in Jakarta, Indonesia

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Abstract
Thermal comfort study has been conducted in two Jakarta's private universities, namely Tarumanagara University (Untar) and Mercu Buana University (UMB). Ninety architecture students involved in this study, collecting 900 thermal votes from various indoor temperature conditions. Comparing to the previous study done in Jakarta in 1993 the result of this study was quite different, subjects were comfortable in much lower temperature. Even when compared with the previous study in Bandung with a lower outdoor temperature, subjects' comfort temperature in this study was about similar.. Since the study has also collected information about the use of AC by the subjects in their accommodations, this study revealed that nearly 100% subjects of Untar students had been using AC in their accommodations, while for the UMB students less than 50% subjects had been living in AC accommodations. This paper discusses the whole study and draws some conclusions from it.
Keywords: air conditioning (AC), undergraduate students, Indonesia, thermal comfort

1. Introduction

Jakarta is the capital of Indonesia located at 6^o South Latitude which is close to the Equator. It has two seasons throughout the year: dry and rainy seasons. Since this city is in the warm, humid tropical climate, the diurnal and annual climatic variations are very small. In the rainy season the daily outdoor temperature is between 22 and 32^oC while in the dry season is about 24 to 34^oC. The temperature variations between the two seasons is very little. The monthly average outdoor temperature is then about the same throughout the year, although in the rainy season the outdoor temperature is slightly a bit lower than in the dry season. This kind of condition also happens in other cities throughout the country. Based on this condition, using the monthly average outdoor temperature as a factor to measure the degree of thermal adaptation can be fairly acceptable in this study.

Like in other developing countries, the economic development of Indonesia raises some concerned about the uncontrolled use of energy. In the past, most of the low income people in this country were unable to use some of the modern technology like AC. Today, people are becoming richer and are easily getting the access to cool their houses and buildings by installing AC. Even in a number of low income houses, AC is something that commonly used today.

Within the past 20 years, the use of AC in the houses and buildings has been escalated dramatically in this country. Even there are no available data to support this statement, it would be uneasy to find a non AC building in the Indonesian towns today. Children from the haves born in this period of time have certainly experienced their whole life in the AC rooms, either in their houses or in the buildings, where they commonly used everyday like classrooms, library, shops, and other public buildings.

The phenomena of the changes of the immediate environment like building, from naturally ventilated (NV) to air conditioned, would be predictable changing the comfort temperatures required by the people. The changes of the indoor air temperatures, from high or medium levels in the NV building to become a low level in the AC building would be predictably reduce the comfort temperature required by the people. This study is an attempt to see these phenomena, whether a lower indoor temperature in the building due to the use of AC would affect to the decrease of people comfort temperature.

In order to do that, thermal comfort study was conducted in two Jakarta's private Universities namely Tarumanagara University (Untar) and Mercu Buana University (UMB). These two universities are different mainly on the students' economical background. With about twice as expensive as its tuition fees, Untar students, mostly come from the haves families, while UMB students mostly come from the middle income families.

2. Methodology

Comfort measurements in Untar were carried out on 29 April 2013 (the beginning of the dry season) and 11 September 2013 (the beginning of the rainy season), while the measurements in UMB took place on 22 May 2013 (about in the dry season). Both Untar and UMB campuses are located in Jakarta and they are separated each other by about 10km.

The measurements both in Untar and in UMB were carried out in the lecture rooms which were modified slightly to resemble a 'thermal chamber'. The rooms were blocked from any air infiltration from the outside. To have such indoor climatic variations, the rooms were firstly cooled by split-AC machines before use for the measurements. Students were asked to enter the classrooms and sit inside about 10 minutes after the AC had been turned off, aiming to provide a homogeneous indoor temperature.

There were 54 architecture students consisted of 30 males and 24 females involved in the Untar study and collecting 468 comfort votes. Students were entering the room about 10 minutes after the AC machines were turned off. The students took their seats and engaging in light activities like reading and chatting. In UMB, there were 36 students of 20 males and 16 females involved in the study, collecting 432 comfort votes. Like in Untar, students were entering the room about 10 minutes after the AC machines in the room were turned off. The students took their seats and engaging in light activities like reading and chatting. In total both studies have involved 90 subjects of Architecture students, collecting 900 thermal votes from various indoor temperature conditions.

All the measurements in Untar and UMB were using exactly the same instruments: alcohol thermometers measures air temperature, a 15cm-diameter globe thermometer painted black using alcohol thermometer to measure radiant temperature (globe temperature), a digital thermo-hygrometer to measure air relative humidity and a digital indoor anemometer to measure air velocity. In every measurement all the instruments were placed on the wood chair at about 80 cm from the floor and located about in the middle of the room.

In Untar study, 17 different indoor climatic parameters (air temperature, globe temperature, relative humidity and air movement) were measured using instruments described above. Along with the measurements of indoor climatic parameter, subjects' thermal sensations were measured at the same time by using a seven-scale thermal sensation vote: Cold (-3), Cool (-2), Slightly cool (-1), Neutral (0), Slightly warm (+1), Warm (+2) and Hot (+3). There were 54 subjects involved in the Untar study, collecting 468 thermal votes.

Figure 1. Measurements in Untar

In UMB study, measurements were conducted similarly to that of Untar in which 12 different indoor climatic parameters (air temperature, globe temperature, relative humidity and air movement) were measured using the same instruments as Untar. Along with the indoor climatic parameter measurements, subjects' thermal sensations were measured at the same time by using a seven-scale thermal sensation vote: Cold (-3), Cool (-2), Slightly cool (-1), Neutral (0), Slightly warm (+1), Warm (+2) and Hot (+3). There were 36 subjects involved in the UMB study, collecting 432 thermal votes.

Figure 2. Measurements in UMB

A number of ways to calculate subjects' neutral (comfort) temperature are available. ISO 7730-2005 (ISO 7730, 2005) defines these terms into three categories A, B and C in which A category is defined as PPD<6% and PMV>+0.2, the B category is defined as PPD<10% and PMV>+0.5 and the C category is defined as PPD<15% and PMV>+0.7.

However, this paper would not use this way to classify comfort conditions, rather it will be applying a rather simple way to define subjects comfort temperature and comfort range. In this study, neutral or comfort temperature (T_n) is defined as AMV (actual mean vote) equals to zero or 95% of subjects would be felt neutral, while the comfort range would be defined in two categories A and B. The A category of comfort range T_{cr} (A) is defined as AMV is between -0.5 and +0.5 or about 90% of subjects felt neutral, while the B category of comfort range T_{cr} (B) is defined as AMV is between -1 and +1 or about 75% of subjects felt neutral. The correlation between the AMV values and the percentage of the number of subjects would be felt comfortable is based on ISO 7730-2005 (ISO 7730, 2005).

3. Data and Analyses

3.1. Data of subjects

Subject of Untar study consists of 30 males and 24 females, made up the total of 54. Table 1 shows the statistical data of Untar subjects. From Table 1 it can be seen that Untar subjects were between 19 and 24 year of age with an average of 20.7 years and standard deviation (SD) of 0.98 years. In terms of height, the shortest subject was 152 cm and the tallest was 185cm with an average of 167.4cm and SD of 7.12 cm. Subjects' weights were between 44 and 105kg with an average of 63.1kg and SD of 12.7kg. The DuBois area or the body surface area (BSA) of the subjects formulated as BSA = $(W^{0.425} \times H^{0.725}) \times 0.007184$ is calculated by using BSA calculator of Cornell University School of Medicine (Cornell University, website, 2014) were found to be between 1.38 and 2.1 m^2 with the average of 1.71 m^2 and SD of 0.18m^2.

Table 1. Data of Untar subjects

	Age (yr)	Height (cm)	Weight (Kg)	DuBois area (m^2)
N	54	54	54	54
Min	19	152	44	1.38
Max	24	185	105	2.1
Mean	20.7	167.4	63.1	1.71
Standard Deviation (SD)	0.98	7.12	12.7	0.18

In the UMB study, there were 36 students involved in this study, consisting of 20 males and 16 females. Table 2 shows data on UMB subjects. It can be seen from Table 2 that subjects were between 18 and 25 year of age with an average of 20.4 years and SD of 1.69 years. In terms of height, the shortest subject was 148 cm and the tallest was 180cm with an average of 165.6 cm and SD of 6.13 cm. Subjects' weights were between 40 and 80kg with an average of 54.4kg and SD of 8.44kg. The DuBois area of the subjects was between 1.29 m^2 and 1.93 m^2 with an average of 1.59 m^2 and SD of 0.17m^2.

Table 2. Data of UMB subjects

	Age (yr)	Height (cm)	Weight (Kg)	DuBois area (m^2)
N	36	36	36	36
Min	18	148	40	1.29
Max	25	180	80	1.93
Mean	20.4	165.6	54.4	1.59
Standard Deviation (SD)	1.69	6.13	8.44	0.17

3.2. Data of indoor climatic parameters

Table 3 shows the indoor climatic data of Untar study. The indoor air temperatures were between 22 and 30^oC with an average of 26.2^oC and SD of 2.67^oC, while the globe temperatures were between 19 and 29^oC with an average of 24.5^oC and SD of 3^oC. The indoor RH ranged between 60 and 70% with an average of 66.9% and SD of 4.1%. Measured by an anemometer, it was also noticed that the indoor air was still during the measurement.

Table 3. Data of indoor climatic parameters of Untar study

	Air temperature T_a (^{o}C)	Globe temperature T_g (^{o}C)	Relative humidity RH %	Air Velocity (m/s)
N	17	17	17	17
Min	22	19	60	Negligible (Still)
Max	30	29	70	
Mean	26.2	24.5	66.9	
Standard Deviation (SD)	2.67	3	4.1	

Table 4 shows the indoor climatic measurement in UMB. The indoor air temperatures were between 23 and 30^{o}C with an average of 27.3^{o}C, while the globe temperatures were between 21 and 29.5^{o}C with an average of 24.5^{o}C. The indoor RH ranged between 67 and 80.8% with an average of 71.7%. As in Untar, it was noticed that the indoor air was still during the measurement.

Table 4. Data of indoor climatic parameters of UMB study

	Air temperature T_a (^{o}C)	Globe temperature T_g (^{o}C)	Relative humidity RH %	Air Velocity (m/s)
N	12	12	12	12
Min	23	21	67	Negligible (Still)
Max	30	29.5	80.8	
Mean	27.3	24.5	71.7	
Standard Deviation (SD)	2.03	2.64	4.4	

3.3. Distribution of subjects' thermal sensation

Table 5. Distribution of subjects' thermal votes of Untar study

Measurement	**Temperature**		**Thermal vote**								**No of subject**
	Air Temp (^{o}C)	**Globe Temp (^{o}C**	**-3 Cold**	**-2 Cool**	**-1 Slightly cool**	**0 Neutral/ comfort**	**+1 Slightly warm**	**+2 Warm**	**+3 Hot**	**Mean vote**	
1	22	19	0	1	12	15	2	0	0	-0,4	30
2	24	21	0	0	1	20	7	2	0	0,3	30
3	25,5	22	0	0	1	17	10	2	0	0,4	30
4	26	24	0	0	1	10	13	6	0	0,8	30
5	26,5	25	0	0	0	6	12	12	0	1,2	30
6	27,5	26,5	0	0	0	4	12	13	1	1,4	30
7	28	28	0	0	0	4	10	15	1	1,4	30
8	29	28	0	0	0	1	10	14	5	1,8	30
9	29,5	28,5	0	0	0	1	5	18	6	2	30
10	30	29	0	0	0	1	6	16	7	2	30
11	22	22	2	6	7	8	1	0	0	-1	24
12	24,5	23	0	1	6	13	4	0	0	-0,2	24
13	26	25	0	0	3	11	10	0	0	0,3	24
14	27	26	0	0	0	13	10	1	0	0,5	24
15	27,5	26,5	0	0	0	11	11	2	0	0,6	24
16	28	27	0	0	0	11	9	4	0	0,8	24
17	28,5	27,5	0	0	0	7	11	6	0	0,9	24
Total			2	8	31	153	143	111	20		468
Percentage			0.4%	1.7%	6.6%	32.7%	30.6	23.7	4.3%		100%

Table 5 shows the distribution of subjects' thermal votes of Untar study. Within the air temperature of between 22^{o}C T_a and 30^{o}C T_a and globe temperature of between

19°C T_g and 29°C T_g subjects' thermal votes were distributed in such a way in which out of 468 votes, 153 (32.7%) were neutral, nearly 60% of thermal votes were in the warm and hot sides and only less than 10% were in the cool sides. This means that the subjects were likely to be comfortable within the temperature, which is closer to 22°C T_a (or 19°C T_g) than to 30°C T_a (or 29°C T_g).

Table 6 shows the distribution of subjects' thermal votes of UMB study. Within the range of air temperature of 23°C T_a and 30°C T_a and globe temperature of between 21°C T_g and 29.5°C T_g subjects' thermal votes were distributed in such a way in which out of 432 votes, 114 (26.4%) were neutral, about 67% of thermal votes were in the warm and hot sides and only about 7% were in the cool sides. This means that the subjects were likely to be comfortable within the temperature, which is closer to 23°C T_a (or 21°C T_g) than to 30°C T_a (or 29.5°C T_g).

Table 6 Distribution of subjects' thermal votes of UMB study

Measurement	**Temperature**		**Thermal vote**								**No of respondent**
	Air Temp (°C)	**Globe Temp (°C**	**-3 Cold**	**-2 Cool**	**-1 Slightly cool**	**0 Neutral/ comfort**	**+1 Slightly warm**	**+2 Warm**	**+3 Hot**	**Mean vote**	
1	23	21	2	4	11	16	3	0	0	-0.6	36
2	25	23	0	2	2	25	7	0	0	0	36
3	26	24	0	0	4	19	12	1	0	0.3	36
4	26.5	25	0	0	3	11	19	3	0	0.6	36
5	26.5	26	0	0	1	12	19	4	0	0.7	36
6	27	26.5	0	0	0	9	22	5	0	0.9	36
7	27.5	27	0	0	0	5	24	6	1	1.1	36
8	28	27.5	0	0	0	7	21	7	1	1.1	36
9	28.5	28	0	0	0	5	16	15	0	1.3	36
10	29.5	29	0	0	0	4	8	24	0	1.6	36
11	29.5	29.2	0	0	0	1	3	24	8	2.1	36
12	30	29.5	0	0	0	0	2	19	15	2.4	36
Total			2	6	21	114	156	108	25		432
Percentage			0.5%	1.4%	4.9%	26.4%	36.1%	25%	5.8%		100%

3.4. Neutral temperature and comfort range

3.4.1. Neutral temperature and comfort range of Untar study

Fig 3 shows the regression line of comfort votes against air temperature (T_a). This regression produces an equation of AMV = 0.316T_a - 7.628, with a coefficient of determination (R^2) of 0.457. The correlation between AMV and T_a is significant at 0.01 level (2-tailed).

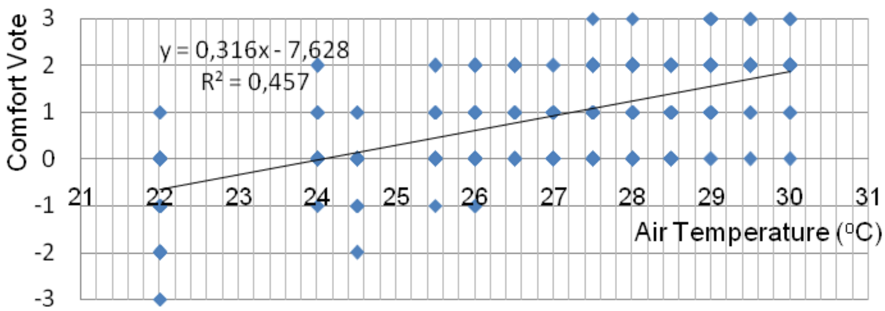

Fig 3 Regression line of thermal vote on air temperature

Figure 4 shows the regression line of comfort votes against globe temperature (T_g). This regression produces an equation of AMV = 0.231T_g - 5.019, with a coefficient of determination (R^2) of 0.376. The correlation between AMV and T_g is significant at 0.01 level (2-tailed).

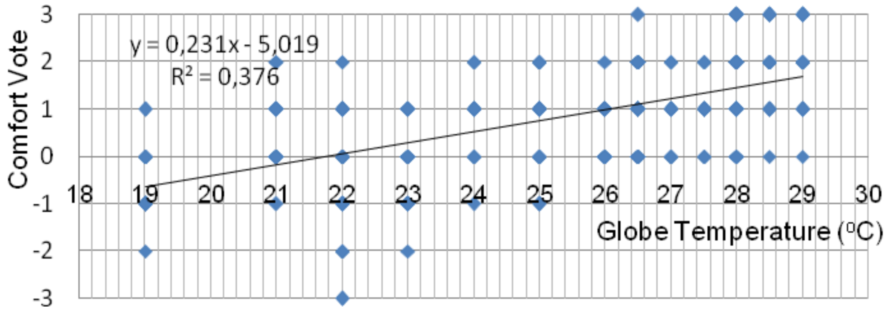

Fig 4 Regression line of thermal vote on globe temperature

Table 7 shows the neutral (comfort) temperature and comfort range of the Untar subjects. From this table it can be seen that in terms of air temperature, subjects neutral temperature of Untar study is 24.1°C T_a, while T_{cr} (A) is 22.6 - 25.7°C T_a and T_{cr} (B) is between 21 – 27.3 °C T_a. While in terms of globe temperature, subjects neutral temperature of Untar study is 21.7°C T_g, while T_{cr} (A) is 19.6 to 23.9°C T_g and T_{cr} (B) is between 17.4 – 26.1 °C T_g

Table 7. Neutral temperature (T_n) and comfort range (T_{cr}) in terms of air and globe temperature of Untar study

	T_a (°C)	T_g (°C)
Neutral temperature (T_n, ± 95% comfortable)	24.1	21.7
Comfort range A (T_{cr}, ± 90% comfortable)	22.6 – 25.7	19.6 – 23.9
Comfort range B (T_{cr}, ± 75% comfortable)	21 - 27,3	17,4 – 26,1
Regression equation	Y = 0,316X – 7,628	Y = 0.231X – 5,019
Coefficient determination (r^2)	0,457	0,376

3.4.2. Neutral temperature and comfort range of UMB study

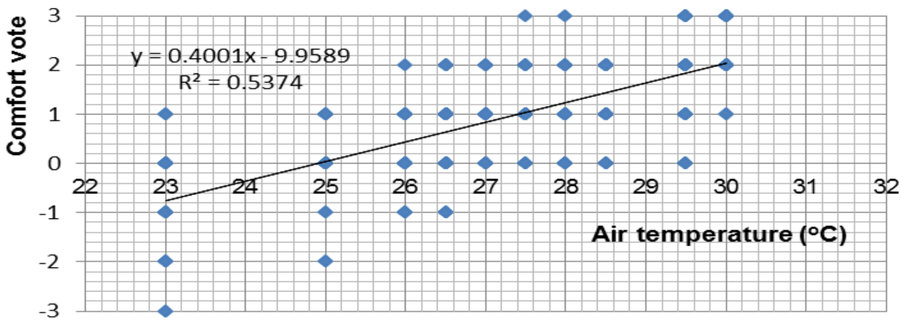

Fig 5 Regression line of thermal vote on air temperature

Fig 5 shows the regression line of comfort votes against air temperature (T_a). This regression produces an equation of AMV = 0.4001T_a - 9.9589, with a coefficient of determination (R^2) of 0.537. The correlation between AMV and T_a is significant at 0.01 level (2-tailed).

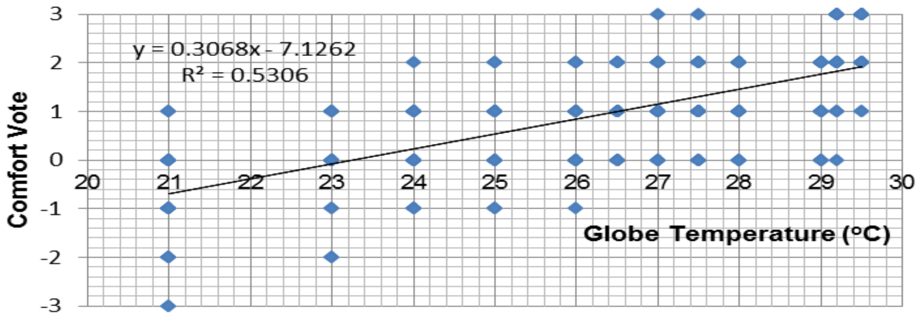

Fig 6 Regression line of thermal vote on globe temperature

Fig 6 shows the regression line of comfort votes against globe temperature (T_g). This regression produces an equation of AMV = 0.3068T_g – 7.1262, with a coefficient of determination (R^2) of 0.531. The correlation between AMV and T_g is significant at 0.01 level (2-tailed).

Neutral (comfort) temperature and comfort range of the UMB subjects are calculated from the regression equations in Fig 5 and 6 and they are presented in Table 8. It can be seen from the table that in terms of air temperature, subjects neutral temperature of UMB study is 24.9°C T_a, while T_{cr} (A) is 23.6 to 26.1°C T_a and T_{cr} (B) is 22.4 to 27.4 °C T_a. While in terms of globe temperature, subjects neutral temperature of UMB study is 23.3°C T_g, while T_{cr} (A) is 21.7 to 24.9°C T_g and T_{cr} (B) is 20 to 26.6 °C T_g

Table 8. Neutral temperature (T_n) and comfort range (T_{cr}) in terms of air and globe temperatures of UMB study

	T_a (°C)	T_g (°C)
Neutral temperature (T_n, $\pm$ 95% comfortable)	24.9	23.3
Comfort range A (T_{cr}, $\pm$ 90% comfortable)	23.6 – 26.1	21.7 - 24.9
Comfort range B (T_{cr}, $\pm$ 75% comfortable)	22.4 – 27.4	20 - 26.6
Regression equation	Y = 0.400 – 9.958	Y = 0.306 – 7.126
Coefficient determination (r^2)	0.537	0.53

4. Discussions

Looking through Tables 7 and 8 we can see that subjects' comfort temperature of Untar study was 24.1°C T_a (21.7°C T_g) while the UMB study was 24.9°C T_a (23.3°CT_g). The results of this study were quite surprising. Although the study was conducted in Jakarta with the mean monthly outdoor temperature of about 28°C, subjects' comfort temperature was found to be much lower than that of the comfort study done in Jakarta in 1993 (Karyono, 2000). To be compared with a previous comfort study in Bandung in 2006 (Karyono, 2008) with a lower monthly outdoor temperature of 24°C T_a, subjects' comfort temperatures of Untar and UMB were about similar to that of Bandung study.

Since the recent Jakarta study collected also the information about whether subjects were using AC in their accommodations, this study revealed that nearly 100% subjects of Untar students using AC in their accommodations, while for the

UMB students less than 50% subjects having AC in their accommodations. All the classrooms, both in Untar and UMB were air conditioned.

It can be seen in Table 5 and 6 that the classrooms' temperatures in both Untar and UMB were usually being set at about 22 and 23^oC (at the beginning of the measurements, after the AC were just about to be turned off). Since the subjects were having such daily experiences in a quite low classroom temperature, it is predicted that subjects would be comfortable in a low temperature, which is close to 22 and 23^oC as in the classroom's temperatures they usually experienced.

In the case of Untar, where nearly 100% of the subjects live in the AC accommodations, it can be predicted that the subjects would have experienced in the similar situation as in the classrooms. While for the UMB subjects, there would be only some of them would have a similar thermal condition as in the classroom as only some of them living in the AC accommodations. Therefore, it was found in this study that the UMB subjects were comfortable, or achieving neutral temperature, in the slightly higher temperature than the Untar subjects.

Comfort study done in Jakarta by the author in 1993 (Karyono, 2000) showed that comfort temperature of subjects, who were about the same age as the students in this study, was 26.4^oC T_a and this is about 1.5 degrees higher than this studies in the two Jakarta's universities. The college-age subjects in the 1993 Jakarta study were low-rank workers in their offices and came from low-medium income families which, predictably had no AC in their accommodations. While, a previous comfort study in 2006 in Bandung (Karyono, 2008) with an average monthly outdoor temperature around 23^oC showed that subjects' comfort temperature was 24.7^OC. Since Bandung average daily and monthly temperature were quite low, not many people would have AC in their accommodation. The indoor temperature in Bandung would be similar or slightly higher than the outdoor, resulting in the low subjects' comfort temperature in that study.

Some thermal comfort studies show that comfort temperature is affected by the average running temperature that a person experiences (Nicol, 1993). Into some extent, the higher the average running temperature experienced by a person, the higher the comfort temperature would be for this person (Nicol, et al, 2012). People live in the tropical environment tend to have a higher comfort temperature than those live in the temperate climate. Assessing some studies conducted by a number of researchers in some South East Asia countries, Karyono (Karyono, 1996) found that the comfort range was between 20 and 31^oC, higher than the average comfort range in the temperate region. In 2010 Humphreys et al comparing data from comfort studies done after 1978 and the Humphreys' graph of 1978 (Nicol, et all, 2012). It was found that the mean comfort temperature for any given outdoor temperature has risen by about 2K. Whatever the reason, this was predicted that there was a changing in the indoor temperature that people experienced which leads to the changes of their comfort temperature.

At the moment result of this study looks in line with the Adaptive rule that physically people tend to adjust to their thermal environment where they have been exposed for a long time.

5. Conclusions

It was found from the study that comfort temperature of Untar subjects in this study was 24.1^oC T_a (21.7^oC T_g) while the UMB subjects was 24.9^oC T_a (23.3$^oC T_g$). These figures are lower than the previous comfort study done in Jakarta in 1993. Furthermore, these comfort temperatures are also found to be similar to the comfort temperature of Bandung students lived in a lower monthly average outdoor temperature.

This study has shown that there is a decreased by about 1.5K on the college-age students' comfort temperature within the last two decades. Although this is still a matter of speculation, a decrease of about 1.5 degrees could have been caused by the changes of the indoor thermal environment that the subjects have experienced from warm to cool due to the use of massive air conditioners in the buildings within the last 20 years.

If this is the case, the massive use of AC in the buildings within the last two decades seems likely has decreased the comfort temperature requirements of people live in the big city like Jakarta. It could be possible that people tend to be more comfortable at a lower temperature than before as they have been exposed to the lower temperature environment. The improvement of the peoples' economy gives more people the chance to have more access to the use of modern technology like AC, lowering the indoor temperature and reducing people thermal comfort requirements. This could cause to the escalation of building energy consumption in the developing countries like Indonesia.

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