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Adaptive Thermal Comfort in The Tropic: A Case Study of The Aceh Tsunami Museum

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Abstract - Thermal comfort calculated using ISO 7730 has been questioned and responded by more adaptive thermal comfort methods. This study was therefore conducted to assess the acceptable thermal comfort for the local people in the tropical Aceh using the measurement based on ISO 7730 and with adaptive thermal comfort method by questionnaires. In this research, Aceh Tsunami Museum building, located in Banda Aceh, Indonesia, was in an open designed layout to be assessed as a case study. This study was conducted onsite using mechanical equipment and involving 138 respondents. The result shows that the comfort temperature calculated by mechanical equipment based on ISO 7730 is 23.14^{0}C. This is in contrast with the result of the questionnaires that showed people in an open building design rate the air temperature up to 32^{0}C as slightly cool. This condition is influenced by the mean air speed of 2.34 m/s and the mean relative humidity of 66.25%. This finding agrees that obtaining the comfort air temperature especially in tropics merely from the prediction of comfort index in ISO 7730 is inaccurate since the respondents actually could adapt with the higher air temperature.

Keywords: Adaptive thermal comfort; Tropics; Aceh Tsunami Museum

Introduction

Determining neutral temperature in order to obtain thermal comfort has already been studied by some researchers. The old method in determining thermal comfort was proposed by Fanger (1970) as exactly described in ISO 7730 through the use of the PMV (Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfied) indices. The PMV predicts the mean value of the votes of a large group of people on the ISO thermal sensation scale such as +3 = hot; +2 = warm; +1 = slightly warm; 0 = neutral; -1 = slightly cool; -2 = cool; -3 = cold. The PPD predicts the percentage of a large group of people who are likely to feel 'too warm' or 'too cool'. Yet this method has been questioned in recent years because it is based on testing the subjects in special test rooms, rather than observations in general buildings (Nicol *et al*., 2002).

The lack of significance on the methods for determining thermal comfort in field trip and in the naturally ventilated environments, in which mechanical equipment is not present, has contributed to some studies in developing a more flexible comfort standard, widely known as Adaptive Thermal Comfort (ATC). The fundamental assumption of ATC is expressed by the adaptive principle: '*if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort'* (Nicol *et al*., 2002). This suggests that the comfort temperature is the result of the interaction between the subjects and the building or other environment they are in. 'The option for people to react will reflect their situation: those with more opportunities to adapt themselves to the environment or the environment to their own requirements will be less likely to suffer discomfort' (cited from Bedford, 1936 in Nicol *et al*., 2002). Adaptive principle of thermal comfort can be approached by surveys and questionnaires rating the people's thermal sensation upon the measured temperatures.

Some of thermal comfort studies carried out adaptively in tropics are summarized in a number of equations of comfort temperature (T_{co}). The followings are the thermal comfort equations proposed by Humphreys (1981), Auliciems (1989) and Nicol and Raja (1997) based on field studies in free-running buildings and in warm climates. Table 1 shows the thermal comfort equations indicating that peoples sense the comfort air temperature by adapting themselves to the outside monthly air temperature. In other words, it can be said that high outside air temperature may result in high comfort temperature. Being a warm humid country, Indonesia applies the method of ASHRAE 1997 adopted in Indonesian standard (SNI T 03-6572-2001) ranged as follows:

- Comfortably cool: 20.5 *ET*- 22.8 *ET*
- Optimally comfortable: 22.8 *ET* – 25.8 *ET*
- Comfortably warm: 25.8 *ET*-27.1 *ET*

Table 1. Equations of comfort temperature (T_{co})

Models	Equations of comfort temperature (T_{co})
Humphrey	T_{co}= 0.53T_m+ 11.9 (r= 0.97)
Auliciem	T_{co}= 0.48T_i+ 0.14T_m+ 9.22 (r= 0.95)
Nicol's first survey	T_{co}= 0.38 T_o+ 17.
Nicol's second survey	T_{co}= 0.36 T_o+ 18.5

Notes: T_{co} - comfort air temperature (^{0}C); T_m - outside monthly air temperature (^{0}C); T_i - mean inside air temperature (^{0}C); T_o – outside air temperature (^{0}C)

The ranges are narrow and lower than the comfort temperature proposed by Karyono (1996) who carried out his study in air conditioned and free running office in Jakarta (the capital city of Indonesia). The comfort temperature obtained was 23.9^{o}C-29.7^{o}C based on the PMV range -1<PMV<1 (-1 = slightly cool; 1 = slightly warm).

Banda Aceh which is located at 5.51, longitude has different local climate from Jakarta. There has never been a study to find the comfort temperature in Banda Aceh. The need to find the comfort temperature in Banda Aceh is essential, since the people's life style has shifted to be better economically meaning that the people will pay any amount to be comfortable. Currently in Aceh, there is a common view in using of air conditioning in concrete public buildings. This is very contrast to the traditional habit which optimally received thermal comfort from the natural environment of the local climate. The excessive dependence on air-conditioning to provide the comfortable indoor temperatures will badly affect the outside environment. In spite of the money spent, the greenhouse effect will worsen the hot humid environment.

This paper therefore aims at assessing the acceptable thermal comfort of the local people in a naturally ventilated environment in Banda Aceh by using two methods of measurements firstly, measurement using mechanical equipments based on ISO 7730; and adaptive thermal comfort measurement using questionnaire. Aceh Tsunami Museum was chosen as the test bed since it represents the naturally ventilated public building designed with an open layout. The findings will show how the public building should perform to achieve comfort.

The enviromental aspect of Aceh Tsunami Museum

The design concept of the museum is coined as 'building as an escape hill' which resembles traditional Acehnese house featuring raised floor to symbolize the survival of Acehnese during the tsunami. The museum is a 2,500 sqm four-storey structure. The shape imitates the Shipwreck diesel power (PLTD Apung ship), a huge electric generator ship that got carried by the sea waves to be displaced as far as 10km inland into Banda Aceh town by the tsunami. The walls of the museum are adorned with images of people performing Saman dance creating lots of apertures to allow the flow of air to cool the museum. The first floor of the museum is an open public space. The large pond in the middle of the ground floor and the high ceiling are designed to contribute to indoor thermal comfort. The characteristics of the museum which are similar to the vernacular approach of Acehnese traditional house in the museum apply the passive cooling strategy. Evaporative cooling is adopted in the museum through the large pond positioned in the middle of the ground floor without walls. This gives a direct contact between the outside air with the water. All rooms in the upper floors can view the pond through the void (Figure 1).


(a)


(b)

Figure 1: The Aceh Tsunami Museum (a. Interior design, b. Exterior design)

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The Aceh Tsunami Museum is situated in Banda Aceh, the capital city of the Province of Aceh located at the north western tip of the island of Sumatra, Indonesia with latitude 5.51, longitude 95.41, and altitude 21 metres. Based on BMKG data in 2008, the average temperature, humidity and air speed in Banda Aceh are 27 ^{o}C, 78% and 2m/s, respectively. The average precipitation amount in this given year is 100.6mm with the highest average of rain frequency occurs in November, December, January and March (Sari *et al.*, 2010). The features of the museum were built to suit the tropical nature of the area, which was thought to be quite challenging as the peak temperature can reach 36 ^{o}C, as noted in July, 2009 by BMKG.

Materials and Methods

The thermal comfort assessment in the Tsunami Museum was conducted using the methodology shown in Figure 2. The thermal comfort assessments were carried out using questionnaires and followed simultaneously by thermal measurement conducted in the morning, noon and afternoon inside the museum for two days (3-4 June 2009). Banda Aceh has no significant fluctuations of climatic condition, therefore the two days measurement may represent the whole days within a year especially in the dry month. The questionnaire consisted of questions on age, sex, clothing and the respondents' activities during the survey. The respondents were also asked to rate their thermal sensation on a seven-point like scale [(-3) cold, (-2) cool, (-1) slightly cool, (0) neutral, (+1) slightly warm, (+2) warm and (+3) hot. Measurements of the thermal parameters were carried out applying the ISO 7730 standard with using Thermal Comfort Data Logger type 1221, Center 310 RS-232 Humidity Temperature Meter, and Anemometer as shown in Figure 3. The mechanical equipment shown in Figure 3 measured the following thermal parameters.

The measurements were only conducted on the ground floor where passive cooling strategy is in place. The schematic diagram of the measurement setup is shown in Figure 4. The inside and outside measurements on each position were conducted from 9.00-16.30 over 2 days. The readings were taken at 1 minute intervals on each position inside the building and 10 minutes outside the building. The thermal comfort data logger was also used to predict the thermal sensation using the theory in ISO 7730. The results from the mechanical measurement and from the survey-questionnaire were then compared to find out how the thermal sensation of the people in the field differs from the thermal sensation predicted by ISO 7730.

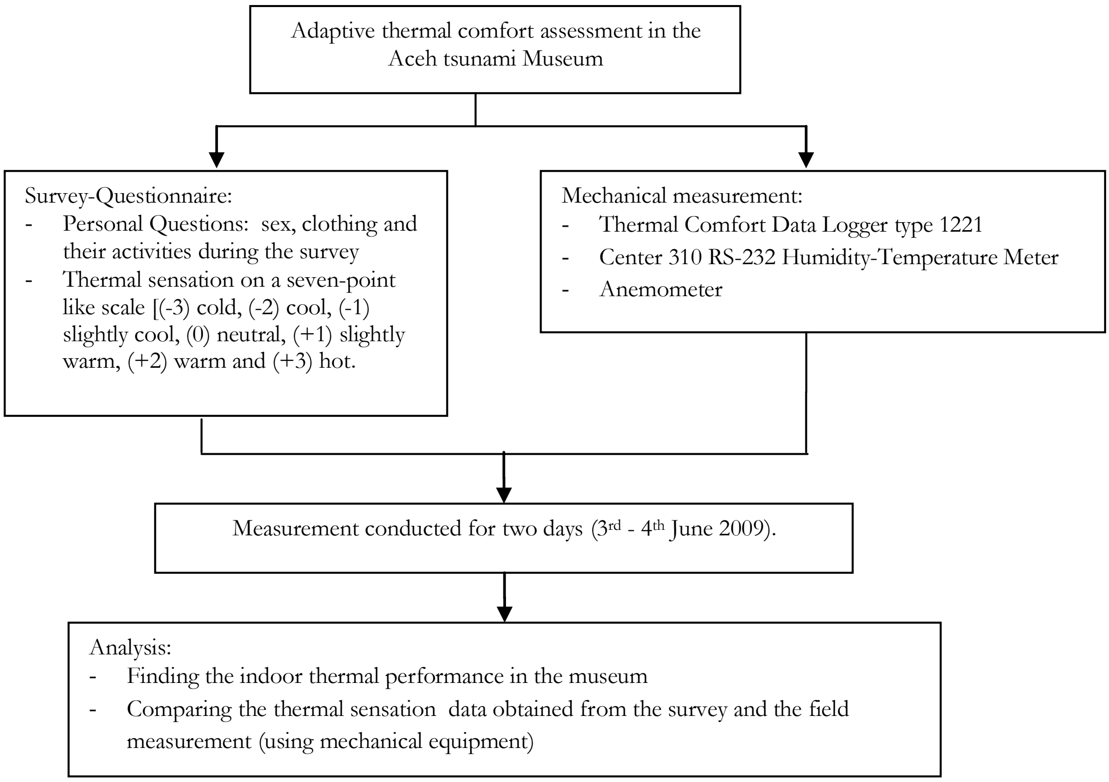

Figure 2. Flowchart of the research methodology

(a)

(b)

Figure 3. Measuring equipments: (a). Center 310 RS-232 humidity temperature meter, and anemometer, (b). thermal comfort data logger type 1221

Table 2. The thermal parameters measured in the study

Physical parameter/abbreviation	Meaning
V_o	Outside air velocity (m/s)
T_{ao}	Outside air temperature (^{0}C)
T_{ai}	Inside air temperature (^{0}C)
T_{oi}	Inside operative temperature (^{0}C)
T_{eqi}	Inside equivalent temperature (^{0}C)
V_i	Inside air velocity (m/s)
RH_o	Outside Relative Humidity (%)
RH_i	Inside Relative Humidity (%)
PPD	Predicted Percentage Dissatisfied (%)
PMV	Predicted Mean Vote

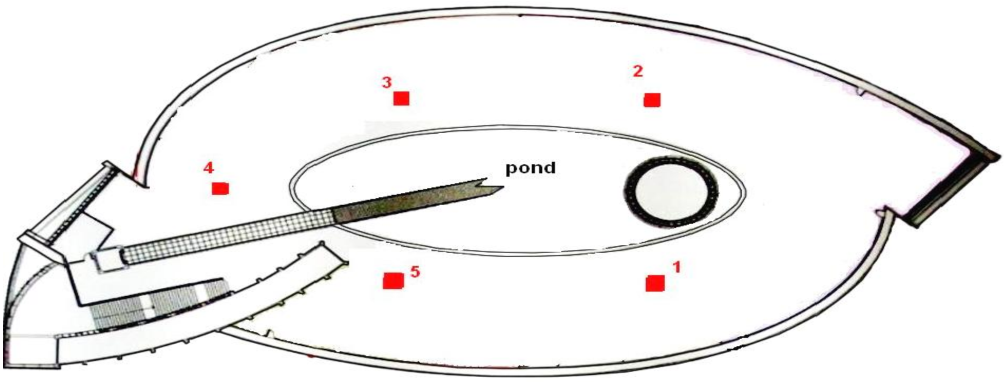

Figure 4. Ground Floor Plan of Aceh Tsunami Museum indicating locations where measurement took place.

Results and Discussion

Indoor thermal performance

The average results of the measurement are shown in Table 3. It reveals that open layout building such as Aceh Tsunami Museum can provide a lower indoor air temperature, which is 8.29^{0}C lower than the peak outdoor air temperature during the measured day. While in average the outside air temperature reduced is 3.7^{0}C. The building design was proved to work effectively to reduce the indoor air temperature. The design of the building also allows the outdoor air to flow freely into the museum giving average of 2.3 m/s indoor air speed compared to 2.6m/s outside the building. The average value of indoor relative humidity is 66.2%, which is slightly higher than the outdoor value, i.e. 61.3%.

Table 3. The measured indoor thermal performance of the museum.

Measuring time		Average value									
Dates	Hours	Tao (ºC)	RHo (%)	Vo (m/s)	Tai (ºC)	Toi (ºC)	Teqi (ºC)	Vi (m/s)	RHi (%)	PPD (%)	PMV
03/06/2009	09:01	33	64	0.5	29.6	29.5	28.0	0.9	66.5	27.2	1.0
	10:01	38.5	48.1	0.92	30.6	30.6	28.6	4.6	56.8	32.4	1.1
	11:01	34.6	47.1	2.03	31.2	31.0	29.8	1.4	53.0	48.4	1.5
	12:01	36.7	46.6	2.32	31.6	31.4	30.1	2.3	55.0	53.9	1.6
	13:01	37.9	43.3	0.94	31.9	31.9	30.8	2.4	57.6	67.8	1.8
	15:01	27	85.2	4.85	27.0	27.1	24.2	2.2	78.0	6.3	-0.3
	16:01	26.9	86.5	4.89	26.7	26.9	23.8	2.3	85.5	8.3	0.4
04/06/2009	09:01	36.9	52.5	0.6	28.6	28.5	27.3	0.5	59.2	52.2	1.5
	10:01	37.5	55.8	2.5	30.3	30.2	28.4	2.1	67.7	73.9	1.9
	11:01	32.1	71.1	2.83	29.9	29.9	27.9	2.9	76.5	65.1	1.8
	12:01	30.2	77	5.02	29.5	29.3	26.9	3.2	77.9	48.9	1.5
	13:01	33.4	58.2	2.61	30.0	29.9	28.6	0.9	63.0	75.4	2.0
	15:01	33	57.8	4.36	30.4	30.4	28.6	3.3	61.4	76.4	2.0
	16:01	31.6	64.5	2.83	30.8	30.7	28.8	3.7	69.4	80.5	2.1
	Average	33.52	61.26	2.66	29.86	29.81	27.99	2.34	66.25	51.19	1.42

Thermal sensation

The prediction of thermal sensations during the two day measurement was also recorded. This prediction is formulated in PMV and PPD values which are calculated by the Thermal Comfort Data Logger Type 1221 applying the ISO 7730 as also shown in Table 3. As already mentioned, the real thermal sensations were also recorded from the subjective survey of the visitors at the museum. As many as 138 respondents at the ground floor participating in a 2-day study were asked to rate their thermal sensation on the measured hours. During the survey, most of the respondents wore light clothing (Clothing value: 0.8 clo) and did light activities such as standing and sitting (metabolic rate: 1.2 met). This was the condition when the respondents answered the questionnaire. These two versions of thermal sensation (from the mechanical measurement and from the survey-questionnaire) are shown in Figure 5 and Figure 6.

Figure 5 and Figure 6 shows that there is a significant difference between the predicted and the measured values. The PMV values measured by the equipment were mostly obtained above 1 which indicated 'mostly warm' sensation. However the real thermal sensation rated by the building occupants from the questionnaire can be seen to be -1.5 on average, which means 'nearly cool' sensation. The thermal sensation may be due to the evaporative cooling from the central pond and the adaptation of respondents with the local climate. In addition, Table 3 shows that by using ISO 7730, the average indoor air temperature of the museum during the days of the measurements was 29.86ºC which is regarded as warm (PMV= 1.42); and the average of PPD value toward the value is 51.19% which means that only 51.19% of the respondents are uncomfortable with such temperature.

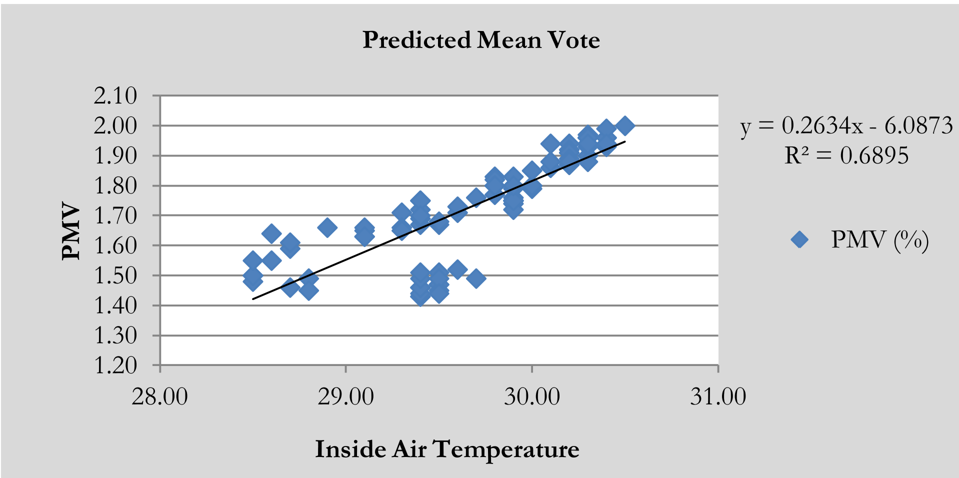

Figure 5. The PMV value recorded by the measuring equipment

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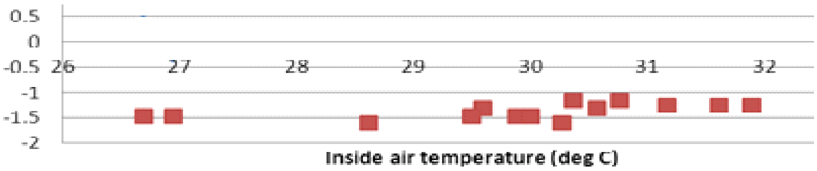

Figure 6. The mean thermal sensation (PMV value) rated by the respondents

Comfort temperature

Figure 5 shows that the linear regression of thermal sensation calculated by the mechanical equipment is PMV= 0,263 x t_{ai} - 6,087. This formula calculates the comfort temperature of Banda Aceh in open building as 23,14^{0}C (PMV = 0). While for the category of slightly cool to slightly warm (-1≤PMV≤1) the range temperature is 19,34^{0}C-26,9^{0}C. This comfort temperature is very low compared with the comfort temperature calculated using the formula of Humphrey, Auliciem and Nicol's models (table 4). The value is also much lower than the comfort temperature proposed by Karyono ranging the comfort temperature for Jakarta as 23.9^{o}C-29.7^{o}C (for the category of slightly cool to slightly warm -1≤PMV≤1). In contrast Figure 6 shows that the real thermal sensation rated by respondents seem to be unpredictable hence no regression linear is formulated. This may be understood that people have their own thermal preference influenced by so many factors such as the previous activities, the clothings, the health etc. Yet, we see from figure 6 that the respondents thermally sensed the air temperature up to 32 ^{0}C, with the mean air speed of 2.34 m/s and the mean relative humidity of 66.25% as slightly cool. It explained that in tropical Banda Aceh, an open building design gives an acceptable positive effect on people toward higher air temperature. This study shows that the design of Aceh Tsunami Museum has successfully contributed the acceptable indoor thermal comfort.

Table 4. Predicted comfort temperatures (T_C) calculated by applying the formulae based on the Humphrey, Auliciem and Nicol's models (Nicol and Raja, 1997; Nicol and Humphreys, 2010)

Humphrey (°C)	Auliciem (°C)	Nicol (°C)	Nicol (°C)
26.21	27.33	27.26	28.22

Conclusions

This paper aims at assessing the acceptable thermal comfort to local people in naturally ventilated environments in Banda Aceh using two methods of measurements e.g measurement using mechanical equipments based on ISO 7730 and adaptive thermal comfort measurement using questionnaire. Aceh Tsunami Museum in Banda Aceh was assessed as it represents the naturally ventilated public building which is designed in open building layout. This study presents the indoor thermal performance of Aceh Tsunami Museum. The museum designed in open layout evaporated with the pond in the center of the building can reduce 4^{0}C of inside air temperature. However, the inside relative humidity and air velocity are not significantly reduced. The average values remained in an acceptable zone e.g. 66.25% and 2.34 m/s respectively to create comfort. Another finding shows that there is a significant difference of thermal sensation between the value obtained from the mechanical measurement based on ISO 7730 and the value measured through survey and questionnaires. Thermal comfort index calculated using ISO 7730 predicted a higher thermal sensation therefore a lower predicted comfort temperature e.g. 23.24^{0}C. It is very contrast to the real thermal sensation rated by respondents which regarded the air temperature of 32^{0}C as slightly cool. This study supports the previous thermal comfort studies finding the comfort air temperature through survey which is automatically influenced by the adaptive thermal sensation of the respondents.

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