Indoor Thermal Assessment of Post Tsunami-Housing in Banda Aceh, Indonesia

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Abstract. The purpose of the study is to see and evaluate the annual indoor thermal performance of post tsunami housing in Banda Aceh, Indonesia by comparing the data with the annual inside thermal performance of unaffected existing house and Acehnese traditional house and the neutral temperatures in tropics. This study is approached by analysing the results of a field survey carried out using questionnaires, onsite measurements, and the relevant literatures. The further analysis in predicting the annual indoor thermal performance was conducted using TAS thermal analysis simulation software. The finding show that there is no significant difference in inside air temperature between the post-tsunami housing and the unaffected existing housing (except traditional Acehnese houses). This study performs the actual indoor thermal performance in the post tsunami housing for couple of days and the predicted annual data of the houses simulated using TAS software. This information is valuable for both the government and Non-Governmental Organizations who carried out the post reconstruction programs in performing their 'products' (donated houses) dealing with the long term local climate.

Keywords: Post tsunami housing, Indoor thermal performance, and thermal comfort

Introduction

Banda Aceh, the capital city of Aceh province, Indonesia was attacked by the 2004 tsunami. The destruction was so massive that remains 60,065 death tolls and 21,412 damaged houses in the city (Nurdin, 2006). As the aftermath, there were various organizations either local or international involved in contributing aid and relief for the tsunami victims with some 120 NGOs (Non-Governmental Organizations) contributing to housing construction (Steinberg, 2007). The various donors created various house types and designs.

In this study, an assessment of indoor thermal performance in post tsunami housing was carried out. This is conducted since the main emphasis of building regulations (e.g BRR, 2006; Aceh Building code, 2005; etc) proposed to be applied seems to have been on rapid construction and making the buildings strong against earthquakes (Arup, 2006; Lubkowski, *et al.*, 2009). Thermal comfort seems to have been a lesser priority in building these post-tsunami houses in Aceh. With regard to the thermal aspect, a paper was published locally showing that the indoor thermal performance of two post-tsunami houses exceeds the thermal comfort of Indonesian building standard based on ISO 7730 (Nawawi, 2006), another paper concerns the assessment of tents used as the temporary dwelling for tsunami victims in Aceh (Zulfian et al, 2006). Apart from these, there have been no thermal assessments of these houses over a longer duration. Consequently, the aim of this study is to assess the indoor thermal performance and to compare that performance to the unaffected existing house and Acehnese traditional house; and Adaptive Comfort Standard (ACS) which complies with natural ventilation supplied building in a tropical zone.

Banda Aceh is located at the north-western tip of Indonesia, at latitude 5.51, longitude 95.41, and the average altitude 8 metres. Based on data for the year 2008 (BMKG, 2008), the average temperature, humidity in Banda Aceh are 27°C, 78% respectively. The average precipitation amount in this given year is 100.6 mm with the highest average of rain frequency occurring in November, December, January and March. The prevailing wind predominantly blows to south east with average wind speed is 2 m/s. (Sari, 2010). In this study, the measurement using the weather data was carried out in year 2009. The simulation was also set up to use the weather data in this year. Corresponding with this, the complete weather data of year 2009 was obtained from BMKG

(Meteorology office) in Banda Aceh. During this year the slightly warmer months and hence lower relative humidity is April, May, June, July, September, and October. Meanwhile, the air speed and cloud remain almost uniform throughout the year.

Materials andMethods

This study is approached by analysing the results of a field survey carried out using questionnaires, onsite measurements, and the relevant literature. The further analysis in predicting the annual indoor thermal performance was conducted using TAS thermal analysis simulation software. The thermal measuring process was conducted utilising the equipment described in Table 1.

Data collection was carried out from May 11th to July 19th 2009 in 208 post tsunami houses in the selected sub districts of Banda Aceh, namely Jaya Baru, Kuta Alam, Kuta Raja, Meuraxa, Lueng Bata and Syiah Kuala. The sub districts except Lueng Bata are chosen because they suffered the worst tsunami effect and therefore bigger number of houses built for the tsunami victims. Meanwhile Lueng Bata was chosen since the measured 'Budha Tzu Chi' house was located there.

Table 1. Measuring equipments

Parameters	Method	Equipment	Interval (min.)	Lay out
Inside air temperature and relative humidity	The logger collected data over two days in both living and bedroom	295-061 Thermal Data humidity logger - model HTB	10 minutes	The loggers were located 1-2 m above the floor (body-head height) in a secure place to avoid them being disturbed by the occupants during the 2 days data collection.
Surface temperature	Collecting data manually over one hour during morning and afternoon	Minolta/ land (infra-red- mean radiant temperature meter)	10 minutes	This measuring equipment was held manually to measure the data in living room, bed room and kitchen.
Air velocity	Collecting data manually over one hour during morning and afternoon	Testo 415 (Temperature and air movement meter)	10 minutes	
CO_2 contamination	Collecting data manually over one hour during morning and afternoon	Testo 535 (CO2 measuring equipment)	10 minutes	
Indoor illuminance	Collecting data manually over one hour during morning and afternoon	Testo 1330 (Digital lux meter)	10 minutes	

The data collection is divided in to two groups explained as follows:

Group 1

A total of 20 houses from those sub districts were surveyed with questionnaire and measuring equipment for 2 days each (picture 1). In order to provide a good comparison three existing houses which were not destroyed by the tsunami as well as another newly reconstructed house and four Acehnese traditional houses were measured for 8 to 40 days. The houses selected are convenient sample since the measurements for those houses were taken over a longer duration than the other 20 houses, hence easy access to those houses was be obtained by selecting previously known households (Mugo, 2002).

I8:IOM/ lightweight	M6: Muslim Aid/ lightweight	BT10: Budha Tzu chi/ lightweight	U2: Uplink/ lightweight	Y4: YBI/ lightweight
				
UE5: Saudi Arabia/ heavyweight	T3: Turkish red Crescent/ heavyweight	B1: BRR/ heavyweight	W7: World Vision/ heavyweight	UA9: UN Habitat/ ADB/ heavyweight
				

Figure 1. The House Types surveyed over two days (Each of type was represented by 2 different houses)

Group 2

Another survey carried out with questionnaires and one hour thermal measurement during morning and afternoon involved up to 188 houses in several sub districts in Banda Aceh. This is done so as to understand the general performance of house quality and people's satisfaction with their houses related to environmental issues. The questionnaire was also conducted to find the occupant's thermal sensation of the houses during morning, afternoon, evening; and during the dry and the rainy seasons throughout the year.

Results and Discussion

Onsite Measurement

In this study we found that most of the houses were built in $36m^2$. This is the house area recommended by Indonesia government to be built free for the tsunami victims (Steinberg, 2007). Meanwhile the major house design is grounded permanent house which is built in heavy weight construction such as plastered brick work. In this study 79.8% of the surveyed houses were heavy weight, 7.7% semi-permanent which is constructed from cemented brick combined with timber; and another 12.5% is light weight house which is built with lightweight materials such as GRC and plywood sheet. The air temperature performances in the twenty houses measured over 2 days are shown as follows:

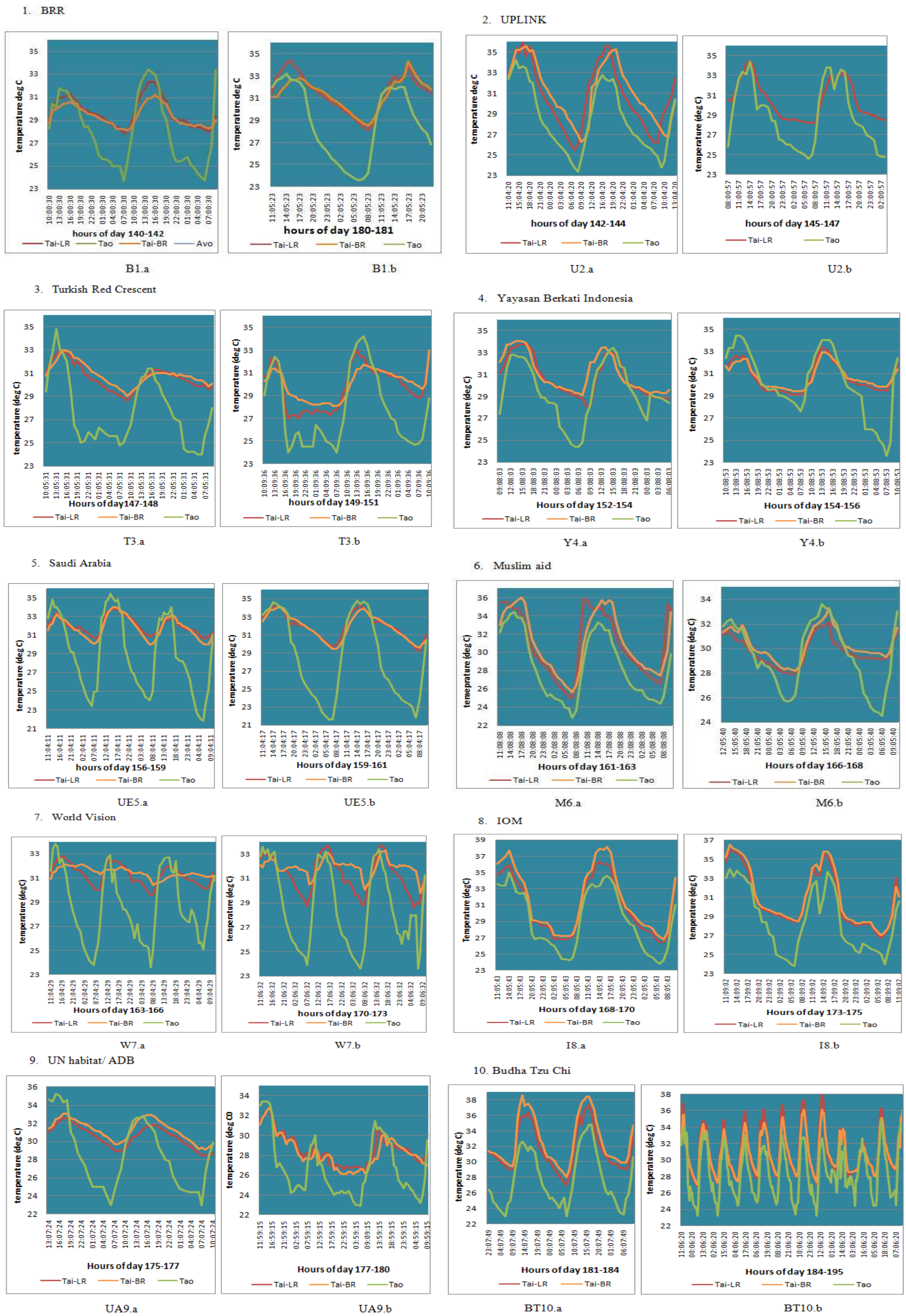

Figure 2. Inside and outside temperatures of the ten house types (the reference numbers refer to the house types illustrated in figure 1).

Figure 2 shows that the heavy weight house such as B1, T3, UE5, W7, and UA9 tend to have the slightly lower peak inside air temperature during the day and conversely higher than the outside air temperature when the sun goes down. In contrast, light weight houses such as M6, I8 and BT10 have an extremely high inside air temperature which is up by 5^0C higher than the outside air temperature. Semi-permanent houses such as U2 and Y4 also tend to have higher inside air temperature, however the value is slightly lower compared with the value in the light weight house. The two house types (light weight and semi-permanent) have lower inside air temperature than the value in heavy weight house when the sun is down.

Table 2 shows the overall performance of temperature difference between the outside air temperature and the inside surface temperature. The heavyweight house shows that the ceiling has the lowest ability in reducing the outside temperature meaning that it suffers the highest surface temperature, followed by glass, wooden door, floor, and wall respectively. The lightweight house shows that all surfaces except the floor have higher temperature than the outside air temperature with the highest one being measured at the ceiling. This would be expected since warm air rises and would contribute further convective heating to the ceiling. The higher surface temperature of the building envelopes during the day is also caused by the character of lightweight materials that warms up quickly when the sun shines in or the heating comes on; and conversely cools down equally as fast (Bird, 2010).

Table 2. Mean surface temperatures

		Mean Air velocity			mean surface temperature					t dif (surface temperature-tao)				
House types	Outside Air velocity	Living Room	Bed Room	Tao	Wall	Ceiling	Floor	Glass	Door	Wall	Ceiling	Floor	Glass	Door
B1	2.00	0.11	0.08	31.2	31.6	37.1	31.7	34.1	32.9	0.4	5.9	0.5	2.9	1.7
U2	2.22	0.11	0.10	31.9	34.0	36.0	32.8	34.4	33.0	2.1	4.1	0.8	2.5	1.1
T3	2.35	0.23	0.11	30.1	31.5	34.3	31.6	34.3	32.3	1.4	4.2	1.6	4.2	2.2
Y4	3.72	0.21	0.11	32.3	33.2	34.6	30.9	34.4	32.6	0.9	2.3	-1.4	2.1	0.4
UE5	2.79	0.24	0.15	33.2	33.3	39.8	34.9	37.4	33.0	0.2	6.7	1.8	4.2	-0.1
M6	3.18	0.20	0.15	31.9	36.0	33.8	33.3	34.8	33.9	4.1	1.9	1.4	2.9	2.0
W7	3.21	0.17	0.15	31.5	32.4	36.0	31.8	33.6	33.1	0.9	4.5	0.3	2.2	1.6
I8	3.22	0.27	0.12	33.0	36.9	43.8	33.3	35.4	35.8	3.9	10.8	0.3	2.4	2.8
UA9	2.81	0.26	0.18	30.9	31.5	32.5	31.4	32.9	32.1	0.6	1.6	0.5	2.0	1.2
BT10	3.35	0.23	0.06	32.6	33.4	38.6	32.5	33.8	33.4	0.8	6.0	-0.1	1.2	0.8

The average range of air speed 0.06-0.27 m/s is much lower than the outside air speed and too low to have any influence in a warm environment. The houses are shown to have inappropriate openings for allowing the outside air speed to decrease the inside air temperature. Arens *et al.*, (2009) through their extensive survey of air speed in neutral and warm environments found that once thermal sensation is>2.5 (hot), 94.45% of people prefer to have the air speed higher than 0-0.2m/s of air speed range. Even for the 'neutral thermal sensation (0)', about 45.92% of people still prefer the air speed higher than 0-0.2m/s. This confirms the result of this survey which is that only 20% of households feel that the mean rate in their houses is too strong while another 80% feels that it is roughly light.

Assessment of comfort votes and thermal acceptability

The occupant's thermal sensation toward their house are rated using ASHRAE scale, namely -3, -2, -1, 0, 1, 2, 3 representing cold, cool, slightly cool, neutral, slightly warm, warm and hot respectively. This study finds that during the morning most of the householders feel to be slightly comfortable with a score of -0.6 and 0.2. During the afternoon the light weight house suffers the highest vote, about 2.3 (warm-hot), while in the evening the heavy weight house radiates its day heat into the house making it the house suffering the highest thermal sensation among those types, about 1.9 (warm). Nevertheless, during the evening all types are regarded as more than slightly warm (>1). The outside air temperature during the evening is actually lower than during the day, nevertheless people regard their houses as warm; this may be caused by the daytime heat radiated into the house due to the time lag caused by the building envelope material; also because of the lack of air circulation inside the house. During the evening people normally close their windows to prevent the mosquitoes entering their houses, which may result in indoor thermal discomfort. In the dry season, all of the householders regard their houses as warm-hot while in the rainy season they are slightly cool. Even though people feel slightly comfortable during morning, they still prefer to have the cooler thermal sensation as well as during the afternoon and evening shown by the thermal sensation preference less than zero (based on the preference range -1: cooler; 0: no change; 1: warmer).

The most interesting relationship is the correlation between the thermal sensation vote and the quality of house design. During the observation, the researcher found that T3 and UE5 have a better performance compared with other types, at the same time this type is voted 0.33 on the thermal sensation scale by the households which is most thermally comfortable (figure 1). Both of these types are heavy construction using plastered brick as the wall, tiled floor and aluminium roof. They are actually not so much different from other masonry houses; the significant things are these houses are tidily built and attractive. The households of T3 commented that their houses were nice and they got enough air circulation throughout the rooms. The other subjective consideration is its suburban location that is not directly in contact with pollution and other heat emission from traffic. Meanwhile UE5 has a very good performance with high ceiling and good design of ventilation. The mean inside air temperature is actually 31.9^{0}C which is actually not so much different from inside temperatures of other types. Yet, this house is voted thermally comfortable by the households even though some of them use air conditioner in their bedroom during the night.

Meanwhile the average thermal sensation in another in 188 post tsunami houses is concluded in these figures below:

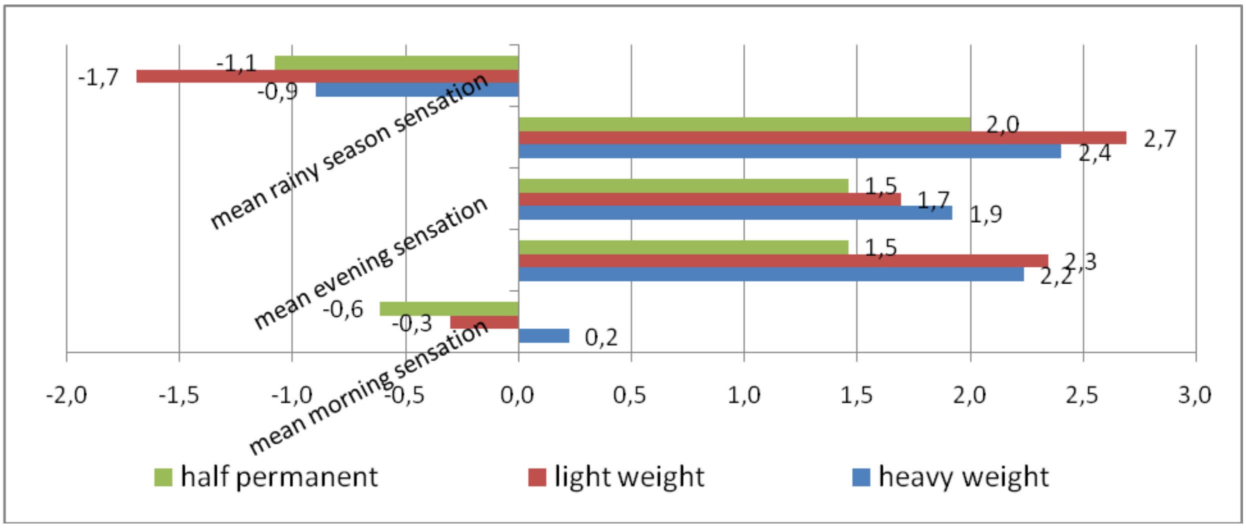

Figure 3. PMV value voted by householders in 188 post tsunami houses

In figure 3 we see that the light weight house mostly suffers the highest thermal sensation votes especially during dry season and all season in the afternoon. While during morning and rainy season almost all house types are rated slightly cool. However, in spite of this people still prefer to have the cooler thermal sensation as well as during the afternoon and evening indicated by the thermal sensation preference less than zero (based on the preference range -1: cooler; 0: no change; 1: warmer).

Comparison of Mean inside temperature

Four Acehnese traditional and three unaffected existing houses were measured for 8 to 40 days. Table 3 summarizes that there is no significant difference in average inside temperature among the three types of those houses (heavy, light weight and semi-permanent). The mean inside temperature of all of those types is 30^0C. Nevertheless, table 3 explains that the heavy weight house, due to its thermal mass character, can have a lower inside air temperature than the outside value. As a result, conversely it has higher minimum temperature when the sun is down. Meanwhile the light weight house works conversely by having the highest inside peak temperature and the lowest minimum temperature among the three house types. The last house type, the semi-permanent house, is likely to have similar peak inside air temperature to the outside value.
This study also shows that Acehnese traditional house has the lowest inside air temperature among the houses. The average inside air temperature is closed to the upper range of Indonesian comfort temperature. It also has lower peak temperature value than the outside one, whereas post tsunami and unaffected tsunami houses are only able to have similar peak inside temperature to the outside ones. This demonstrates that the traditional house has been well designed by understanding the local climate.

Table 3. Mean inside temperature in 3 house types

House category	mean temperature ^{0}C					
	tai-avg	tao-avg	tai-max	tao-max	tai-min	tao-min
Post tsunami -heavy weight house	30.7	28.2	33.3	34.2	28.5	23.2
Post tsunami- semi permanent house	30.6	29.1	34.4	34.1	27.5	23.9
Post tsunami-lightweight house	30.8	28.6	35.9	34.5	26.7	23.5
Unaffected existing -heavy weight house	30.9	28.8	33.8	35.4	27.2	23.4
Unaffected existing - semi permanent house	30.7	28.3	35.8	35.4	26.3	21.6
Unaffected existing -lightweight house	n/a	n/a	n/a	n/a	n/a	n/a
Acehnese traditional house	29.4	28.4	32.7	35.2	25.9	21.8

Neutral temperature

In order to obtain the neutral temperature which then can qualify the inside temperature of each house, the researcher used the data obtained by other studies and employed the model of finding the neutral temperature in natural ventilated buildings of Humpreys, Auliciems and Nicol (Equations 1-4), and the neutral temperature proposed by Karyono based on his study in Jakarta (Karyono, 2000). The adopted equations of Humphrey's and Auliciem's model are outlined briefly by Feriady (2004) such as the following:

- Humphrey's model:

For free-running buildings, the comfort temperature (Tco) can be estimated from the mean monthly outdoor temperature (Tm) in ◦C, through the following equation:
Tco = 0.53Tm + 11.9 (r = 0.97).. (1)
The prediction claims to have a standard error of 1^0C and applies to temperature range of 10 ^{0}C < Tm < 34 ^{0}C.

- Auliciem's model:

By reanalysing Humphrey's data, Auliciems removed some incompatible information, including the results of more recent field studies, and combined data for buildings with both active and passive climate control. The absence of thermal discomfort is predicted by a simple equation in terms of mean indoor (Ti) and outdoor monthly temperature (Tm): Tco = 0.48Ti + 0.14Tm + 9.22 (r = 0.95)…………………………………………………………………………….....(2)
While Nicol's models are outlined by Bouden (2005) as follows:

- Nicol's model:

Based on Nicol's first survey in different climatic conditions in Pakistan, he proposed a relation between the neutral temperature and outdoor temperature through the following equation: $Tc = 0.38\ T_o + 17.0$…………………….…………………………………………………………………(3)

Based on Nicol's second survey in Pakistan, Nicol developed the second regression given by this following equation: $Tc = 0.36\ T_o + 18.5$……………………………………………………………………(4)
The mean outside air temperature used in equations 1-4 is 28.6°C which is the data obtained during the measurement May-July 2009.

Table 4. Comfort temperature comparison

House types	Inside air temperature during the measurement May-July 2009 (°C)		temperature difference (°C)							
			Humpreys tn = 27.1		Auliciems tn = 27.9		Nicol tn = 27.9[a] tn =28.8[b]		Karyono tn = 23.9-29.7[c]	
	peak tai	mean tai	peak tai-tn	mean tai-tn	peak tai-tn	mean tai-tn	Peak [b] tai-tn	Mean [b] tai-tn	peak [c] tai-tn	mean [c] tai-tn
Post tsunami -heavy weight	33.3	30.7	6.2	3.6	5.4	2.8	4.5	1.9	3.6	1
Post tsunami- semi permanent	34.4	30.6	7.3	3.5	6.5	2.7	5.6	1.8	4.7	0.9
Post tsunami-light weight	35.9	30.8	8.8	3.7	8	2.9	7.1	2	6.2	1.1
Unaffected tsunami - heavy weight	33.8	30.9	6.7	3.8	5.9	3	5	2.1	4.1	1.2
Unaffected tsunami - semi permanent	35.8	30.7	8.7	3.6	7.9	2.8	7	1.9	6.1	1
Acehnese traditional	32.7	29.4	5.6	2.3	4.8	1.5	3.9	0.6	3	-0.3

a : Nicol's first survey in Pakistan, b : Nicol's second survey in Pakistan,
c : The upper range of comfort temperature in Jakarta studied by Karyono based on the PMV range -1<PMV<1

By using the formulas and the neutral temperature for Jakarta, Indonesia, table 4 indicates that the mean inside temperature in the traditional Acehnese house is close to the comfort temperature proposed by Nicol and even meets the comfort temperature range proposed by Karyono that may be more applicable, since his work was carried out in Indonesia. Meanwhile, the mean and the peak inside temperatures of post tsunami and unaffected tsunami houses are much higher than any of the comfort temperatures proposed by all of those thermal comfort experts, which supports the views of the 60% of post tsunami house holders saying that their houses are warm-hot.

Predicted Annual Indoor Thermal Performance in Post Tsunami Housing

Five post tsunami house models and an Acehnese traditional houses were simulated using TAS in predicted the annual indoor thermal performance. The simulation applied the following PMV parameters:

- Metabolic rate: 1.2 met (this value applies to light activities, such as standing and relaxing, normally done by the occupants throughout the day).
- External work: 0 W/m² (no external work is applied in this simulation)
- Air velocities, Min: 0.06 m/s; max: 0.31 (these values are the inside air velocity concluded from the field trip measurement conducted in 20 houses).
- Clothing values, min: 0.29 clo; max: 0.38 clo (these values were obtained from the observation during the field trip, that people normally wear very light clothing at home).

To run the simulation, TAS applied Banda Aceh weather data of year 2009 comprising air temperature, relative humidity, air speed, wind direction, and cloud. Whereas the solar data for global and diffuse are adopted from data of latitude 0, Environmental Design, CIBSE A (2006) due to the unavailability of the local meteorology office to provide this. The brief simulation results are shown in Figure 4. It shows that the highest peak inside air temperature occurs in IOM house which is then followed by Uplink house, YBI house, Acehnese traditional house, Saudi Arabia house and World Vision house respectively. Those first four houses are light weight and semi-permanent house; therefore as previously discussed these house types suffer the very high temperature which on average can be up to 40^0C. The inside peak temperatures of those light weight houses occur mostly in July, 26th (day 207) at 3 pm or 4 pm, while the outside peak temperature occurs on August 3rd (day 215) at 4pm. Meanwhile, the air temperature in the heavy weight house has its peak value variously throughout the house zone. The upper zone reaches its peak temperature in July the same time as the light weight house does, while the ground zone has it in August the same as the outside peak temperature.

The average temperature difference between the inside and the outside in the light weight house varied from 0.43-1.75K which is lower than the semi-permanent house (1.37-2.7K) and the heavy weight house (1.94-2.97K) respectively. This small variation is due to the low specific heat capacity and density of the building envelopes especially roof and wall creating no time lag to store thermal energy.

The interesting thing is that in spite of the very high peak temperature, there are 57.7%-68.8% of hours within a year when the PMV values of these light weight houses are regarded as comfortable which is ranged in -1 < PMV < 1 . It is much better compared with the semi-permanent (52.65%-56.61%) and the heavyweight houses (18.32% - 44.94%). This better range is due to the inside air temperature that is quite close to the outside temperature. As the result the inside air temperature stays as cool as the outside temperature during evening, night and in the early morning. The only problem that arises in the light weight house is the inside air temperature during the day, which is almost as high as or even higher than the outside air temperature.

HOUSE TYPE	SIMULATED HOUSES	INSIDE AIR TEMPERATURE (average) (°C)		PMV AND PPD (average) (%)	
		Peak tai	Avg. (Tai-tao)	Comfort range -1 < PMV < 1	Hourly PMV Graph within a year
Heavy weight	World Vision House 	35.2	3.0	18.32	
	Saudi Arabia house 	35.6	1.9	44.94	
Half Permanent	Uplink house 	39.4	2.1	56.61	
	YBI house 	37.6	1.4	52.65	
Light weight	IOM house 	40.1	1.8	57.7	
	Acehnese traditional house 	36.1	0.4	68.84	

Figure 4. Annual indoor thermal performances of some post tsunami houses predicted by TAS building simulation software

Conclusions

The finding shows that there is no significant difference in inside air temperature between the post-tsunami housing and the unaffected existing housing (except traditional Acehnese houses). The inside air temperature values stand higher than the neutral temperature applicable in Indonesia, whereas the thermal value in the Acehnese traditional house is closer to the neutral temperature. This confirms that the post-tsunami housing was built similarly to currently typical houses in Aceh. More concern on applying the building design in tropics is recommended to improve the indoor comfort in free running building such as post tsunami housing built to shelter the victims permanently.

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