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INDOOR THERMAL ASSESSMENT OF POST-TSUNAMI HOUSING IN BANDA ACEH, INDONESIA

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ABSTRACT

Over 100,000 houses were built following the devastation caused by the Tsunami of December 26, 2004. Here the authors investigated thermal comfort in housing built in Banda Aceh, Indonesia, following the widespread destruction of buildings and compared it with undamaged existing houses and a traditional Acehnese house. The study is based on a field survey, questionnaires, and performance simulations. The findings show no significant difference between the post-tsunami housing and the unaffected existing housing, except traditional Acehnese houses which generally performed better.

Key words: Post Tsunami Housing, Indoor Thermal Performance, Thermal Comfort.

Introduction

On 24th December 2004 Banda Aceh, the capital city of Aceh province, Indonesia was inundated by a huge tsunami which caused the loss of 60,065 lives and damaged 21,412 houses in the city (1). In the aftermath many local and international organisations were involved in contributing aid and relief for the tsunami victims, including some 120 NGOs (Non Governmental Organizations) contributing to

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housing construction (2). The various donors created a range of house types and designs, mainly intended for permanent occupation.

In this study, an assessment of the indoor thermal performance in this post tsunami housing was carried out. The main emphasis of the local building regulations (3) seems to be on rapid construction and making the buildings resilient against earthquakes (4, 5), and thermal comfort seems to be a lesser priority. In addition, relatively little work has been done on characterising the thermal performance of buildings in this region; a paper was published locally showing that the indoor thermal performance of two post-tsunami houses did not meet the thermal comfort requirements of the Indonesian building standards based on ISO 7730 (6), while another paper was concerned with the assessment of tents used as temporary dwelling for tsunami victims in Aceh (7). 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, to compare that performance with an unaffected existing house and a traditional Acehnese house, and to assess them on the basis of the Adaptive Comfort Standard (ACS), which applies to naturally ventilated buildings in a tropical zone.

Location and Climate

Banda Aceh is located at the north-western tip of Indonesia, latitude 5.51, longitude 95.41, with an average altitude of 8 metres. Based on data from the meteorology office in Banda Aceh (8), the average air temperature and humidity in Banda Aceh are 27^{0}C and, 78% respectively. The average precipitation in the given year was 100.6mm with the highest rainfall occurring in November, December, January and March. The prevailing wind predominantly blows to the south east with an average wind speed of 2 m/s. (Sari, 2010). The slightly warmer months, and hence those with lower relative humidity, are April, May, June, July, September, and October; the air speed and cloud cover remained almost uniform throughout the year.

Methodology

This study is based on analysing the results of a field survey carried out using onsite measurements and questionnaires. Further analysis conducted using TAS thermal analysis simulation software enabled the annual indoor thermal performance to be predicted. The thermal measurements were conducted utilising the equipment described in Appendix 1.

Data collection was carried out 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 were chosen because they suffered worst from the tsunami and therefore contained the largest number of houses built for the tsunami victims. Meanwhile Lueng Bata was chosen since the ‘Budha Tzu Chi’ house, of traditional Achenese design, was located there, and was also a subject of the comfort survey. The data collection is divided into two groups explained as follows.

Group 1consisted of 20 houses from the sub districts mentioned above which were surveyed using measuring equipment and questionnaires for 2 days each. 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 traditional Acehnese houses, were measured for between 8 and 40 days. The houses selected are a convenient sample since the measurements for those houses were taken over a longer duration than the other 20 houses (9). The second group involved 188 houses in several sub districts in Banda Aceh where the survey was carried out with questionnaires and one-hour thermal measurements during the morning and afternoon. This was done so as to understand the general performance of house quality and people's satisfaction with their houses related to environmental issues. Questions were also asked concerning the occupants' thermal sensation in houses during morning, afternoon, evening, and also during dry and rainy seasons throughout year.

House design and construction

Most of the houses in this study had a floor area of at least $36m^2$, meeting the standards recommended by the Indonesian government (2). The main type of house design is a grounded permanent house built in heavyweight construction such as plastered brick work. Bricks either built in clay or concrete were used on a large scale, much of the demand being then met by training the tsunami victims (local people) to make bricks using the local materials. These programs were carried out through NGOs such as ILO and Architecture clinic and went a substantial way to meeting the need for bricks. As far as can be ascertained, the houses were built to the recommended standards and should therefore be able to withstand any expected earth tremors at least as well as existing houses. In this study 80% of the surveyed houses were heavy weight, 8% semi permanent (constructed from cemented brick combined with timber), and the remaining 12% were lightweight houses built with lightweight materials such as GRC and plywood sheet.

On-site Measurement

The air temperature performance in the twenty houses measured over 2 days is shown in Table 1, which shows that the heavy weight houses such as B1, T3, UE5, W7, and UA9 tend to have a slightly lower peak inside air temperature during the day, but a higher temperature than the lightweight buildings when the sun goes down. In contrast, lightweight houses such as M6, I8 and BT10 have an extremely high inside air temperature which is up to 50C higher than the outside air temperature. Semi-permanent houses such as U2 and Y4, as might be expected, tend to have inside air temperatures in between those of the light and heavy weight houses. The lightweight and semi permanent house types have lower inside air temperature than the heavyweight house when the sun is down.

TABLE 1. Table of living room air temperatures: Outside air temperatures over the measuring period ranged from around 23°C to 33-34°C.

Style of house	Code	Max. living room temp C	Min. living room temp C
Light (traditional)	BT10a	37.0	27.0
Light (traditional)	BT10b	38.0	27.0
Light	I8a	36.0	26.6
Light	I8b	36.0	27
Light	M6a	35.9	26.9
Light	M6b	32.0	28.0
Semi	U2a	35.6	26.8
Semi	U2b	34.0	28.1
Semi	Y4a	33.7	28.1
Semi	Y4b	33.2	29.0
Heavy	UE5a	33.9	30.9
Heavy	UE5b	34.1	29.7
Heavy	W7a	32.9	29.9
Heavy	W7b	34.8	28.8
Heavy	B1a	32.2	28.0
Heavy	B1b	34.1	28.2
Heavy	T3a	33.0	28.8
Heavy	T3b	33.0	27.0
Heavy	UA9a	32.4	28.6
Heavy	UA9b	32.6	26.4

The radiant temperatures of the surfaces also influence the occupant's feelings of thermal comfort, and Table 2 shows the overall temperature difference between the outside air and the inside surface. The heavyweight house shows that the ceiling has the least capacity to reduce the outside temperature, i.e. it suffers the highest surface temperature, followed by glass, wooden door, floor, and wall respectively. In the lightweight house all surfaces except the floor have a higher temperature than the outside air, the highest 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 envelope during the day is also a result of using lightweight materials that warm up quickly when the sun shines, and conversely cool down equally rapidly.

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, and the design of openings such as doors and windows does not allow sufficient air movement to decrease the inside air temperature. Arens et al (10), through their extensive survey of air speed in neutral and warm environments, found that once thermal sensation is >2.5 (hot), 94.4% of people prefer an air speed higher than 0.2m/s. Even for the 'neutral thermal sensation (0)', about 46% of people still prefer an air speed higher than 0.2m/s. This confirms the result of this survey which is that only 20% of households feel that the air movement in their houses is too high, while another 80% feel that it is roughly right.

TABLE 2. Mean surface temperatures.

House types	Outside Air velocity	Mean Air velocity		Tao	mean surface temperature					t dif (surface temperature-tao)				
		Living Room	Bed Room		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

Assessment of comfort votes and thermal acceptability

The occupants' thermal sensation regarding the houses were rated with a 7-point scale as used by ASHRAE, namely -3, -2, -1, 0, 1, 2, 3 representing cold, cool, slightly cool, neutral, slightly warm, warm and hot respectively. This study found that during the morning most of the householders felt fairly comfortable with scores of -0.6 and 0.2. During the afternoon the lightweight house suffered the highest vote, 2.3 (warm-hot), while in the evening the heavy weight house radiates the heat absorbed during the day back into the house resulting in a score of 1.9 (warm). Nevertheless, during the evening all types were regarded as more than slightly warm (>1). The outside air temperature during the evening was lower than during the day, nevertheless people regarded their houses as warm, due to the daytime heat being radiated into the house following the time lag induced 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 mosquitoes entering, reducing air movement and having a negative effect on indoor thermal comfort. In the dry season, all of the householders regarded their houses as warm-hot while in the rainy season they were slightly cool. Even though people feel fairly comfortable during the morning, they still prefer it to be cooler during the afternoon and evening as shown by a negative thermal sensation (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 observations, the researcher found that T3 and UE5 had a better performance compared with other types, based on the measurements, and the thermal sensation vote was only 0.33, which on the thermal sensation scale by the households which was the most thermally comfortable of all. Both of these types are of heavyweight construction using plastered brick walls, and with a tiled floor and aluminium roof. In terms of construction they are not very different from the other masonry houses; possibly more significant is the fact that these houses were regarded by the occupants as being tidily built and attractive. The households of T3 commented that their houses were pleasant and that they had sufficient air circulation throughout the rooms. The other subjective consideration is its suburban location which means that is not directly in contact with pollution and noise from traffic. Meanwhile UE5 has a very good performance with high ceiling and good ventilation design. The mean inside air temperature of 31.90C is not so different from that of other types, yet this house was voted thermally comfortable by the households - although some of them use an air conditioner in their bedroom during the night. The average thermal sensation in the 188 post tsunami houses is shown in Table 3.

TABLE 3. Thermal sensation votes.

	Lightweight	Semi-permanent	Heavyweight
Mean morning	-0.3	-0.6	+0.2
Mean afternoon	+2.3	+1.5	+2.2
Mean evening	+1.7	+1.5	+1.9
Mean rainy season	-1.7	-1.1	-0.9
Mean dry season	+2.7	+2.0	+2.4

From this figure it may be seen that it was mostly the lightweight house that suffered the highest thermal sensation votes, especially during the dry season, and all seasons in the afternoon. During the mornings and rainy season, almost all house types were rated slightly cool, but during the afternoon and evening it was generally felt to be too warm.

Comparison of mean inside temperature

Four traditional Acehnese and three other houses of modern design, all unaffected by the tsunami, were measured for between 8 and 40 days. The results are summarized in Table 4 which shows that there is no significant difference in average inside temperature between the three types of house (heavy, light weight and semi permanent). The mean inside temperature of all types is 30.70C. Nevertheless, table 4 shows that the air temperature inside the heavyweight house can at times be lower than that outside, due to the effect of the thermal mass. Conversely it has a higher minimum temperature when the sun is down. The light weight house has 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 a similar peak inside air temperature to the outside value.

This study also shows that traditional Acehnese house has the lowest inside air temperature among the houses. The average inside air temperature is close to the upper range of the comfort temperature for Indonesia. It also has a lower peak temperature value than that outside, whereas post-tsunami and unaffected houses have peak inside temperature similar to those outside. This demonstrates that the traditional house has been well designed with a good understanding of the local climate.

TABLE 4. Mean inside temperature in 3 house types.

	mean temperature ^{0}C					
House category	**taimean**	**taomean**	**taimax**	**taomax**	**taimin**	**taomin**
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 - light weight 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 - light weight house	n/a	n/a	n/a	n/a	n/a	n/a
Traditional Acehnese house	29.4	28.4	32.7	35.2	25.9	21.8

Neutral temperature

The neutral temperature, i.e. that temperature at which the occupants feel comfortable (zero thermal sensation) has been investigated by a number of researchers, who developed similar but slightly different models to describe it. In order to obtain the neutral temperature which then can qualify the inside temperature of each house, the researcher inserted the measured data into the following models; those of of Humpreys, Auliciems, Nicol (Equations 1-4), and Karyono, based on his study in Jakarta (11).
The adopted equations of Humphreys' and Auliciems' model are described by Feriadi (12) as follows:

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:

$$Tco = 0.53Tm + 11.9 \ (r = 0.97) \qquad (1)$$

The prediction claims to have a standard error of 10C and applies to temperature range of 10 0C < Tm < 34 0C.

Auliciems' 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):

$$Tco = 0.48Ti + 0.14Tm + 9.22 \quad (r = 0.95) \qquad (2)$$

Nicol's models are described 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:

$$Tc = 0.38\ To + 17.0 \qquad (3)$$

Based on Nicol's second survey in Pakistan, Nicol developed the second regression given by this following equation:

$$Tc = 0.36\ To + 18.5 \qquad (4)$$

The mean outside air temperature used in equations 1-4 is 28.6°C which is almost exactly the value obtained during the measurements May-July 2009.
Using the formulae and the neutral temperature for Jakarta, Indonesia, table 5 indicates that the mean inside temperature in the traditional Acehnese house is close to the comfort temperature proposed by Nicol, and also is within the comfort temperature range proposed by Karyono, which is perhaps more applicable, his work having been carried out in Indonesia. The mean and the peak inside temperatures of the post-tsunami and the unaffected houses are much higher than any of the comfort temperatures predicted by all the thermal comfort models, thus confirming the views of the 60% of post tsunami house holders saying that their houses are warm-hot. While the different researchers have produced slightly different models and values of neutral temperature (Table 5b), an important point that emerges is that in all these cases the mean air temperature is higher than the neutral temperature. In order to form an estimate of how well the buildings perform over the year as opposed to a short-term measuring period, software-based simulations were carried out for the building types investigated, which were validated using the short-term data.

TABLE 5a. Comfort temperature comparison.

House types	Inside air temperature during the measurement May-July 2009 (°C)		Temperature difference (°C)							
			Humpreys		Auliciems		Nicol		Karyono	
	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
Traditional Acehnese	32.7	29.4	5.6	2.3	4.8	1.5	3.9	0.6	3	-0.3

TABLE 5b. Table of neutral temperatures derived using models from a range of researchers.

	Humphreys	Auliciems	Nicol (a)	Nicol (b)	Karyono (c)
Neutral Temp C	27.1	27.9	27.9	28.8	23-9-29.7

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: $-1<PMV<1$

<u>Predicted Annual Indoor Thermal Performance in Post-Tsunami Housing</u>

Five post-tsunami house models and a traditional Acehnese house were simulated using the TAS thermal simulation model which was used to predict 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 from the year 2009. A brief summary of the simulation results is shown in Table 6; the highest peak inside air temperature occurs in the IOM house, followed by the Uplink house, YBI house, traditional Acehnese house, Saudi Arabia house and World Vision house respectively. Those first four houses are light weight and semi permanent houses, and as previously discussed they suffer very high temperatures which on average can be up to 400C. The inside peak temperatures of the light weight houses occur mostly on July 26th (day 207) at 3 pm or 4 pm, while the outside peak temperature occurs on August 3rd (day 215) at 4pm.

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; while on the ground floor zone it occurs in August, the same time 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 envelope, especially the roof and wall, with very little thermal storage or time lag.

An interesting point is that in spite of the very high peak temperature, for 57.7%-68.8% of hours within a year the PMV values of these light weight houses are regarded as comfortable, with the range -1 < PMV < 1 . This is much better than the semi permanent (52.65%-56.61%) and the heavyweight houses (18.32% - 44.94%). This is due to the fact that the inside air temperature is quite close to the outside temperature. As a result the inside air temperature remains as cool as the outside temperature during the evening, night and in the early morning. High temperatures at night are not liked as they make sleeping difficult. The main problem arising in the light weight house is that the inside air temperature during the day is as high as or even higher than the outside air temperature. The findings from these simulations are in line with those from the short-term measurements and confirm the better performance of the traditional house.

TABLE 6. Simulated temperatures using TAS.

Type	Code	Peak inside Air Temp C	Mean ΔT inside - outside air temp C	% within -1<PMV<+1
Heavy	W	35.2	3.0	18.3
Heavy	UE	35.6	1.9	44.9
Semi	U2	39.4	2.1	56.6
Semi	Y	37.6	1.4	52.6
Light	I8	40.1	1.8	57.7
Light	BT10 (Trad)	36.1	0.4	68.8

TABLE 7. Measuring equipment.

Variable measured	Method	Equipment	Measurement interval (min)	Location
Inside air temperature and relative humidity	Datalogged over two days in both living and bedroom	295-061 ThermaData temperature and humidity sensor/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 (CO_2 measuring equipment)	10 minutes	
Indoor illuminance	Collecting data manually over one hour during morning and afternoon	Tes 1330 (Digital lux meter)	10 minutes	

Conclusion

The findings show that there is no significant difference in inside air temperature between the post-tsunami housing and the undamaged modern housing, but that the traditional Acehnese houses performed much better in providing thermal comfort for the occupants. The inside air temperature values stand higher than the neutral temperature applicable in Indonesia as predicted by a number of models, whereas the thermal sensation value in the traditional Acehnese house is closer to the neutral temperature. The measurements and the annual simulations confirm that the performance of the post-tsunami housing was similar to that of houses which have been built in recent years in Aceh. Heavyweight houses suffer from high temperatures in the evenings and nights, whilst the lightweight houses have high temperatures during the afternoons, and the traditional house performs better in all areas. There was essentially little difference between the post-tsunami houses and modern houses built before the tsunami; therefore we may conclude that from the thermal comfort point of view the quality of those houses is considered acceptable. However, the much better performance of the traditional houses suggests that the virtues of traditional building styles, which have been developed over centuries of experience, should be re-examined. The use of traditional construction raises other questions, such as the availability local skilled labour, the sustainability of the supply of building materials, and the aspirations of the local populace; anecdotal evidence suggests that many people consider the traditional buildings old-fashioned, and that a building of modern design which include air conditioning are regarded as a symbol of affluence. Additionally, the post-disaster housing was erected in a relatively short space of time, and although the solutions seem to be as acceptable and perform as well as the previously existing housing, it is unlikely that there was sufficient time to produce an optimum solution. Another significant point is that many of the tsunami victims had lost almost all they owned, and may therefore have been grateful for any house in which to live, and so less inclined to complain about some discomfort than those who had not suffered such a loss. Investigation of all these factors would require a further extensive multi-disciplinary study which is beyond the scope of this work.

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