Thermal Comfort Study in Post Disaster Housing in the Southern Coast of Sri Lanka

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Abstract

The Indian Ocean Tsunami in 2004 had a great impact on the local land formation, vegetation and settlement patterns in Sri Lanka. The re-housing developed to settle the displaced people were carried out in mass scale over a period of two to three years. By and large the criteria for re-settlement had little or no consideration for thermal comfort and climate change. This study was conducted with the aim of identifying the features in the building that causes overheating and features that has the potential to mitigate overheating.

A thermal comfort field survey was conducted in selected house types in Boosa and Dadella in Galle, Madihe in Matara and Kirinda in Tissamaharama during the months that presented the most extreme climate conditions during the year. The physical characteristics of thirteen houses were explored; indoor thermal conditions were monitored with the aim of assessing the overall thermal performance of the houses.

Findings showed the need to start at the neighbourhood level and the importance of the building envelope in achieving thermal comfort. Implications for design focus on guidelines for controlling the negative effects of the microclimate into the interior habitable spaces, together with the need for prescriptive thresholds for the building envelope.

***Key words**: Thermal Comfort, Post Disaster Housing, Sri Lanka.*

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1. INTRODUCTION

Sri Lanka was the second most affected country by the Indian Ocean Tsunami 2004, with 35,322 lives lost and 516,150 people displaced. Thirteen districts along the eastern and Southern Coast of Sri Lanka was impacted by the Tsunami which occurred in 2004(ADB et al 2005). Post disaster reconstruction created an opportunity for creating better housing solutions for communities. Concepts such as Build Back Better (BBB) were formally introduced following the disaster. The concept implies the use of a collaborative approach to improve the physical, social and economic conditions of a community during post-disaster reconstruction and recovery. However, the reality was far from ideal. Mannakkara and Wilkinson (2013)explored the concept in the case of Sri Lanka and found that large scale reconstruction was a factor that led to building and construction standards being overlooked. Although some attempts at design guidance and information were made at the initial stages of the re-construction phase (e.g. Emmanuel (ed), 2005) the lack of proper building codes and legal enforcements were contributory to the poor quality of housing and weak structural resilience. These together with a lack of response to the lifestyles and socio-cultural backgrounds of the community, lack of consideration of traditional settlement patterns, housing types and layouts etc have been extensively studied (Mannakkara and Wilkinson, 2013; Ahmed 2011; Tucker, Gamage, Wijeysekara, 2014).

The principles of BBB looks at the macro level of housing quality and resilience in line with its first principle (structural design for better quality housing). At the same time, the quality of housing in its response to the environment and climate are equally important when building back better. The building layouts, orientations, building form, and the use of material can have adverse impacts on overheating of buildings resulting in poor indoor thermal comfort. But these considerations were generally lacking in the post-tsunami reconstruction efforts to direct the housing design towards a more climatically responsive approach. The response to micro climate and thermal comfort within the houses are critical not only for creating good quality housing but also for energy efficiency in housing and as a response to climate change. These become nationally adverse when considering mass scale post disaster reconstruction within a limited time frame.

The present study aims to explore the thermal comfort consequences of post Indian Ocean Tsunami 2004 housing in Southern Sri Lanka with a view to contributing to the development of appropriate guidelines in the future. The need for guidelines that addresses these issues become critical when considering the continuously warming climate trend scenario currently being experienced in Sri Lanka. Such guidelines should also vary based on the location and climatic conditions of disaster risk areas. Hence building back more climatically responsive housing is an important factor to be considered in post disaster reconstruction.

2. BACKGROUND

Buildings account for 35-40% of global energy consumption (EPBD, 2012) and 33% of global carbon emissions (IPCC, 2013). Given the rate of global urbanization (World Urbanisation Prospects, 2014) and the consequent increases in indoor occupation, warming due to global climate change would only increase the occupancy of buildings further, leading to greater energy use (and therefore carbon emissions) (Wan et al., 2011). Concepts such as Bioclimatic design, green or sustainable architecture, and energy conscious design are some pragmatic responses to tackling climate change through the building Industry.

2.1 Thermal comfort

Thermal comfort is an essential factor for creating more comfortable homes. Establishing comfort temperatures of residents can minimize overheating, excessive energy use and save overall energy costs of a household (Rijal, Humphreys and Nicol, 2015). It is one of the primary elements that determines the quality of indoor environment in naturally ventilated buildings and is essential for the health of those who must stay indoors over an extended period of time on a routine basis (Hwang et al., 2009).The development of design strategies and technologies for low energy buildings is critical and architects have a major role to play in creating thermally comfortable, climatically responsive buildings in the face of climate change impacts.

Vernacular methods are more climatically responsive (Santacruz and Lawrence, 2016). The influence of vernacular traditions can be seen in bioclimatic strategies in the works of Luis Barragan where capacitive material and a range of external spaces such as gardens, terraces, porticoes and courtyards are used to provide opportunities for adaptations to warmer conditions, through a range of indoor-outdoor environments (Santacruz and Lawrence, 2016). Lessons for creating climatically sensitive, thermally comfortable buildings can also be drawn through the study of spatial patterns, compositions, use of materials and technology of traditional Sri Lankan architecture. The reinvention of traditional techniques to inform modern building design is well established in Sri Lanka, but design of post disaster housing has not sufficiently drawn from such knowledge (Tucker, et al.,2014).Construction methods in post disaster reconstructions are often deviating from the traditional vernacular construction methods due to demands in the volumes and scale of housing, time and cost constraints. They are often built under extreme and complex conditions where design aspects of housing are often ignored. Aspects such as sustainability and climate responsiveness have low priority in such conditions and opportunities are lost for building better more functional and comfortable housing (Tucker, et al., 2014).

Adebamowow and Ilesanmi (2012) discuss two basic responses such as Mitigation and Adaptation methods for tackling climate change. Mitigation involves mandates for environmental responsibility while Adaptive measures include – structural and behavioural strategies. Structural strategies include flexible and adaptive structural systems; and behavioural strategies include spatial, personal, psychological control measures that influence the design and operation of buildings.

Adebamowow and Ilesanmi, (2012) discuss the need for greater synergy between techno-structural and socio-behavioural dimensions of building adaptations. Study done by Soebarto and Bennets (2014) in Australia discuss the impacts of increasing temperatures on occupant's thermal comfort and subsequent energy use in housing and highlights the crucial role building designs have on occupants comfort. The need for being cooler didn't necessarily translate into using air conditioners but adjusting the clothing was the first action to combat heat. Other passive and low energy design strategies such as opening windows, doors and turning on ceiling fans were the preferred options. Study shows that in the case of low income housing in Australia the use of Air Conditioning was the last resort due to high energy bills and highlights the importance of good design for achieving better thermal comfort in living rooms and bedrooms to mitigate overheating and discomfort. Study by (Adebamowow and Ilesanmi, 2012) on hostel block in Nigeria also shows that responses to preferred adaptive opportunities indicate opening of windows as the most applied adaptive control in dry and wet seasons followed by drinking water, changing clothes, taking a bath, going outside, and switching on AC. The study suggests the occupants' active interventions to increase ventilation rates for improving thermal comfort. Study highlights the need for creating adaptive opportunities which allows occupants to create their own thermal preferences by interacting with the environment, modifying their behaviour or adjusting their expectations to match ambient thermal conditions (Adebamowow and Ilesanmi,2012). Study by Rijal et al., (2015) on adaptive thermal comfort in Japanese houses during the summer season also shows that behavioural adaptations such as window opening, use of fan to increase air movement are useful for improving thermal comfort.

Santacruz and Lawrence (2016) identifies that properties of the building envelope, impact of solar radiation, number of occupants and their behaviour as reasons for poor thermal performance of housing in Mexico – where case study focus on low income housing that uses a concrete form work construction systems in warm – temperate climate. Study also questions the appropriateness of using identical housing prototypes across different climatic regions. The need for context–specific design strategies for adapting buildings to climate change is highlighted by (Adebamowow and Ilesanmi, 2012). Design of the building in terms of its structure, Envelope, interiors, services governs the delicate balance among factors determining comfort conditions.

2.2 Adaptive thermal comfort

Many international studies explore the implications of thermal comfort within housing types and the thermal adaptations of its occupants. Nicole and Humphreys (1972); de Dear and Brager (1998) developed the adaptive comfort theory which posits that factors beyond physics and physiology play an important role in people's thermal preferences. Building occupants are no longer regarded as passive recipients of the thermal environment, but rather play an active role in creating their own thermal preferences. Satisfaction occurs through appropriate adaptation to the indoor climatic environment (de Dear and Brager, 1998). Adaptations are discussed as behavioural adjustments; physiological and psychological (de Dear and Brager, 1998). Behavioural adjustments are classified into personal (such as removal of clothes etc), technological (such as turning on fans, AC), and cultural (such as having a siesta during the heat of the day) (de Dear and Brager, 1998). Physiological adaptations are classified as genetic adaptations and acclimatisation. Psychological adaptations are altered perceptions and reactions to sensory information due to past experiences and expectations.

Occupants could adapt to their environment by adjusting clothing, controls or location, and tolerate environmental conditions outside the thermal comfort standards laid by the "steady state' theories. According to Nicole and Humphreys (2002) Adaptive comfort is defined as a multi-dimensional index depending on other parameters such as interaction of temperature, humidity of different levels of clothing, activity and air velocity. Thermal comfort studies done in naturally ventilated buildings in both tropical and sub-tropical regions including Sri Lanka also suggest that occupants in tropical and sub-tropical regions have a higher temperature tolerance and feel comfortable in warmer environments (Jayasinghe and Halwatura, 2008; Santacruz and Lawrence, 2016).

Adaptive comfort standards define the indoor conditions which occupants will find acceptable for any given outdoor condition. Adaptive Comfort Temperatures are incorporated in commonly accepted standards that specify indoor thermal comfort such as: the ASHRAE Standard 55-2004 (ASHRAE, 2004) CIBSE Guide section A1 2006 (CIBSE, 2006) and EN15251 (2007).

3. METHODOLOGY

The present study assess the overheating and thermal comfort of post disaster housing based on ASHRAE Standard 55-2004 and CIBSE Guide section A1, with the objectives of Identifying the features in the building that lead to overheating as well as to highlight and list the building features that have the potential to mitigate overheating.

3.1 Field work

The study is a survey of 13 selected Post Disaster Houses in 4 locations (3-4 houses at each location) with similar geographical characteristics along the Southern Coast of Sri Lanka during the hot months of the year (September-October, 2016). The locations were selected based on their house types varying in layout, form, material use and other physical characteristics mentioned below.

Two types of data were collected namely; physical data and climatic/thermal data. The physical data of the houses included the location and surroundings, elevation and distance from the sea, building orientation, plot size, house size (square area), house type –such as single house / cluster/ linear arrangement, unit design – detached/ semidetached and vegetation and tree coverage (using a fish eye camera), building form, materials used for structure/walls/floors/roof/doors/ windows and building exterior and interior views. Such data were gathered using a checklist, building plans, section and photographic survey. (See Table 3.1 for the checklist)

Climate data comprised of temperature and humidity measurements of bedroom and living room measured using a Hobo Loggers. Further a weather station was installed outside in a common area of the neighbourhood to record the outdoor weather conditions and to serve as the reference condition. Each house was monitored for a period of 7 days continuously. Monitoring was simultaneously carried out in the selected houses in each location.

The monitored data is assessed against the ASHRAE 55 [2004] and CIBSE Guide A [2015] to assess the thermal comfort range within the case study houses.

Some Premises based on CIBSE Guide A

- •A 'free-running' building is one that, at the time in question, doesn't consume energy for heating or cooling.
- •"during warm summer weather 25^{o}C is an acceptable temperature'"
- •"thermal comfort and quality of sleep begins to decrease if bedroom temperatures rise much above 24^{o}C"
- •"bedroom temperatures at night should not exceed 26^{o}C unless ceiling fans are available"
- •Fans can reduce operative temperature and the reduction depends on fan speed. Air speed of 0.6 m/s could reduce operative temperature by 2^{o} C (More detail could be found in Appendix A - ASHRAE 55 2010).

Table 3.1 below discusses the criteria for assessing internal temperatures in naturally ventilated buildings.

Table 3.1: Criteria for assessing internal temperatures in naturally ventilated spaces

Assessment metric	Source	Criterion	Applicability	Comment
Ideal indoor operative temperature	CIBSE Guide A [2015]	25^{o}C. No threshold	For all free running spaces	For residential it is considered for 24 hours
Dwelling operative temperature	CIBSE Guide A [2015]	Temperature over 26oC- No more than 1% of hours above value.	Sleeping spaces only. In low income uses both living and bed rooms used for sleeping	This study limit the application to night time hours are between 19:00 hrs and 5:00hrs
Dwelling operative temperature	CIBSE Guide A [2015]	Temperature over 28oC- No more than 1% of hours above value.	Living and dining rooms	This criterion is applied for 24 hrs

ASHRAE 55 adaptive model	ASHRAE 55 [2010]	80% and 90% acceptability limit	Naturally ventilated buildings with operable windows and mechanically ventilated building without conditioning the air.	80% is for typical application. 90% is for higher level of thermal comfort

Notes:
Total hours considered for analysis 144. Day time hours 78 (6:00 to 18:00).Night time hours 66 (19:00 to 5:00).
1% of night time occupied hours is approximately 1 hour
1% total occupied hours is approximately 2 hours

3.2 Case Description

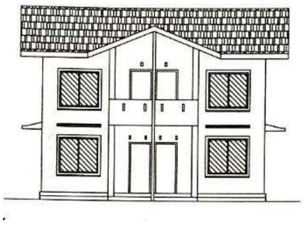
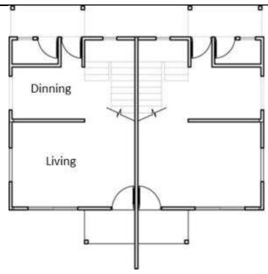
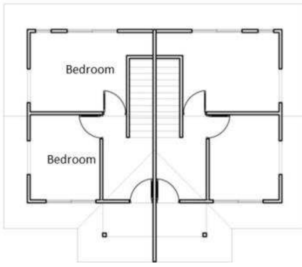
Table 3.1 below shows the description of the 4 selected locations and the settlement type. All selected settlements are post disaster housing constructed after the Tsunami. The locations selected were Boosa, Dadella, Madihe and Kirinda.

Table 3.2: Description of Location and Settlement

Location	**Elevation (m)**	**No of Units**	**Plot Size (Perches)**	**Floor Area (sq. ft.)**	**Cost Per unit (LKR)**	**Distance from coast (km)**	**Unit types**
Boossa 6.0889° N, 80.1561° E	3	Two storey - 23 Single storey - 5	7 perch per unit	650	1.4 M	0.24 km	Twin two storey houses
Dadella 6.0499° N, 80.1999° E	3	48 houses	20 perch	800	1.4 M	0.55 km	Twin house with a mezzanine level
Madihe 5.9333° N, 80.5166° E	3	12 in Madihe 11 in Polhena	Privately owned land. Variable plot sizes	550 - 650	0.6 M	0.24 km	Detached individual houses
Kirinda 6.2352° N, 81.3344° E	3	30 - 100 house	20 perch	800	1.4 M	0.55 km	Detached individual houses

Tables 3.3 to 3.6 shows the house types selected from each location, its orientations and other physical data.

Table 3.3: Physical description of selected houses in Boosa, Galle

	Boosa, Galle - 4 Houses with different orientations were selected for the study from a total of 23 twin -two storey and 5 single storey houses. 					
	 					
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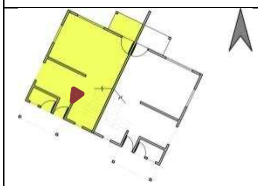	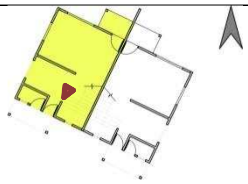		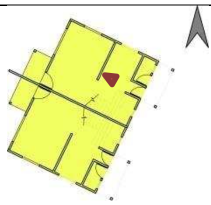		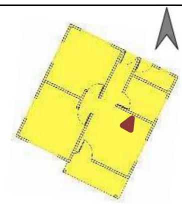 -	
Materials use	Structure	Walls	Roof	Floor	Doors	Windows
	Prefab columns and concrete framework	Reinforced polystyrene concrete panels	Kempus covered with clay tiles	Concrete	Plywood	Aluminium

Table 3.4: Physical description of selected houses in Dadella, Galle

<table>
<tr><td rowspan="2">
</td><td>Dadella, Galle - 3 Houses with different orientations were selected for the study from a total of 40 twin houses with a mezzanine.</td></tr>
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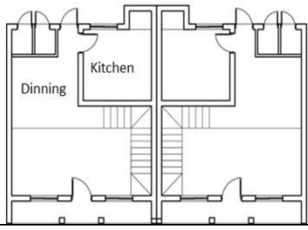
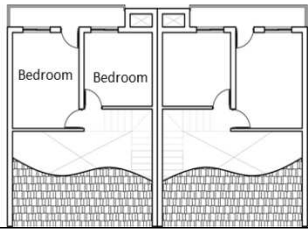
<tr><td>Inset section</td><td>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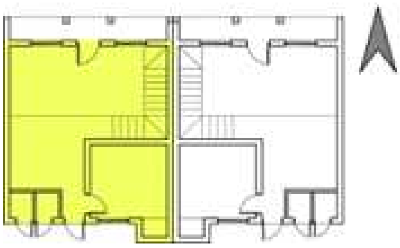
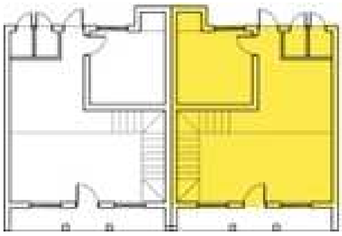
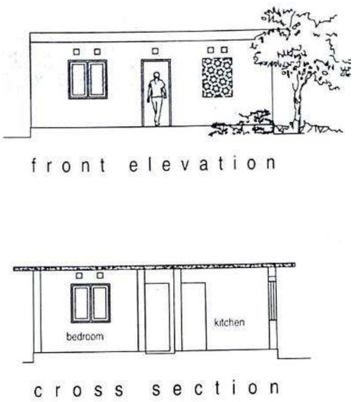
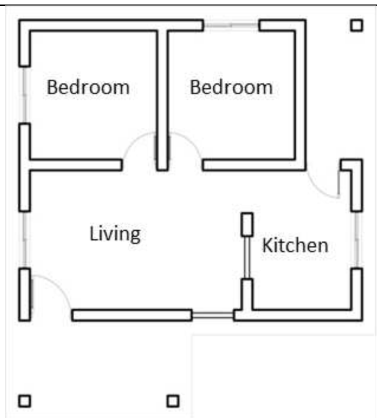
		
– no of floors?/ twin house/ semidetached/ Orientation?/ etc...(physical descriptors)	- no of floors?	

Materials use	Structure	Walls	Roof	Floor	Doors	Windows
	reinforced concrete	cement block / brick	clay tiles on timber framework	Concrete	timber	timber

Table 3.5: Physical description of selected houses in Madihe, Matara

Madihe, Matara - 3 Detached individual Houses with different orientations were selected for the study from 12 houses in in Madihe and 11 in Polhena.





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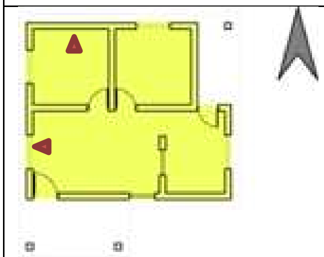	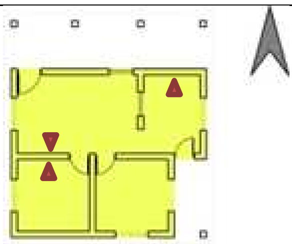	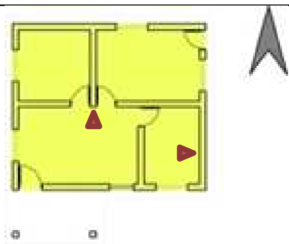

Materials use	Structure	Walls	Roof	Floor	Doors	Windows
	reinforced concrete	burnt bricks	Concrete roof	Concrete	timber	timber

Table 3.6: Physical Description of Selected Houses in Kirinda, Tissamaharama

<table>
<tr><td colspan="2" rowspan="2">
</td><td colspan="5">Kirinda, Tissamaharama – Houses has been designed by renowned Architect Shigeru Ban. 3 Detached individual Houses with different orientations were selected for the study. Site has a total of 100 houses.</td></tr>
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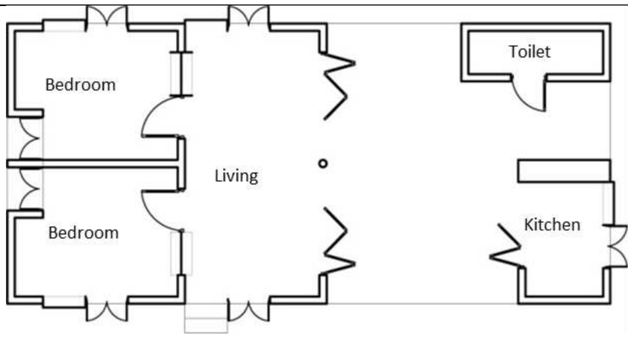
<tr><td colspan="2"></td><td colspan="5">
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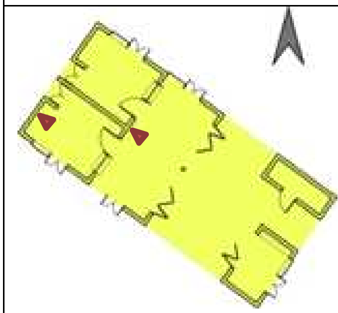
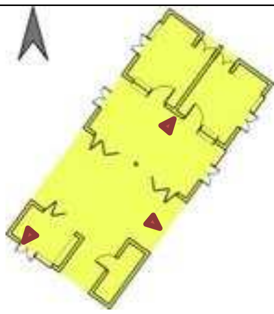
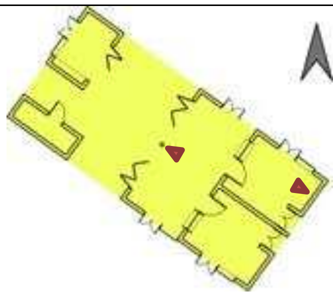
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="3"></td></tr>
<tr><td rowspan="2">Materials use</td><td>Structure</td><td>Walls</td><td>Roof</td><td>Floor</td><td>Doors</td><td>Windows</td></tr>
<tr><td>Timber - coconut columns</td><td>compressed earth brick / timber partitioning</td><td>clay tiles on timber framework</td><td>Concrete</td><td>teak and treated rubber wood</td><td>teak and treated rubber wood</td></tr>
</table>

4. RESULTS AND DISCUSSIONS

4.1 General thermal conditions in the case study houses

Table 4.1 shows the outdoor reference weather conditions during the case study monitoring period. The 'Galle' reference station is representative of three case study sites (Boosa, Dadella and Madihe) while 'Hambantota' station is representative of the conditions outside one case study (Kirinda). It is clear that the latter was warmer and had a larger diurnal range than the former sites.

Table 4.1: Weather characteristics during the monitored period

Description	**Maximum Temp ºC (24 hours)**	**Mean temp ºC (24 hours)**	**Minimum temp ºC (24 hours)**	**Mean daytime º (6:00 to 18:00)**	**Mean night time ºC (19:00 to 5:00)**	**Maximum diurnal range (K)**	**Minimum diurnal range (K)**	**Maximum running mean temp ºC**	**Maximum solar radiation intensity MJ/m²**
Galle	29.6	27.5	25.6	27.8	27.1	3.5	1.1	28.0	3.6
Hambantota	34.9	27.2	21.2	28.2	26.0	10.6	2.9	27.9	3.6

<u>Note:</u>
Galle temperature values are for September 2016
Hambantota temperature values are for October 2016
Solar radiation intensity values for September and October were from Colombo.

Table 4.2 shows indoor temperatures and comfort conditions during the monitoring period. Indoor conditions are given in mean, max and min temperatures plus the diurnal ranges while the thermal comfort measures indicate the number of CIBSE hrs (day and night) over pre-defined thresholds as well as ASHRAE 55: 2004 comfort limits (last two columns). The latter are given in number of hours case study houses were within comfort limits (hrs below 90% acceptability limit – one before last column) and over the comfort limit (hrs above 80% acceptability limit – last column).

Table 4.2: Comparison of internal temperatures measured in September and October 2016, with CIBSE and ASHRAE overheating criteria.

Development/ space reference	Maximum temp °C (24 hours)	Mean temperature °C (24 hours)	Minimum temp °C (24 hours)	Mean daytime temp °C (6:00 to 18:00)	Mean night time temp °C (19:00 to 5:00)	Maximum diurnal range (K)	CIBSE: Hours below 25 °C (24 hours)	CIBSE: Hours over 28 °C (24 hours)	CIBSE: Hours over 26 °C (19:00 to 5:00)	ASHRAE: Hours below 90% upper acceptability limit.	ASHRAE: Hours over 80% upper acceptability limit
Boosa											
BC1GDR	30.9	29.6	28.4	29.6	29.5	2.2	0	144	66	12	50
BC1UBR	32.5	29.8	27.8	30.3	29.1	4.5	0	124	66	49	63
BC2GBR	30.6	28.6	27.1	29.1	28.0	3.5	0	87	66	85	31
BC2UDR	30.7	29.2	28.2	29.4	29.0	2.5	0	144	66	54	35
BC3GDR	29.5	28.8	28.2	28.9	28.8	1.3	0	144	66	78	0
BC3UBR	30.7	29.2	27.9	29.4	29.0	2.5	0	142	66	53	39
BC4SLR	33.0	29.7	27.5	30.2	29	5.1	0	124	66	52	64
Dadella											
DC1GLR	30.7	29.4	28.2	29.6	29.2	2.4	0	144	66	30	42
DC1UBR	33.9	30.7	28.3	31.3	30.1	5.2	0	144	66	15	92
DC2UBR	33.2	30.5	28.5	30.9	30.0	4.5	0	144	66	12	92
DC3GK	30.5	29.7	29.1	29.9	29.6	1.4	0	144	66	0	73
DC3UBR	33.5	30.0	27.5	30.8	29.0	5.7	0	118	66	53	65
Madihe											
MC1GLR	33.9	30.7	38.3	30.9	30.4	4.4	0	144	66	8	109
MC1GBR	31.9	30.4	28.3	30.4	30.3	2.4	0	144	66	6	108
MC2GLR	32.7	29.7	27.5	29.7	29.7	4.0	0	133	66	36	58
MC2GBR	31.5	29.3	27.5	29.2	29.5	2.4	0	130	66	48	45
MC2GK	31.9	29.4	27.5	29.4	29.5	3.2	0	134	66	40	48
MC3GLR	35.0	31.0	27.8	31.5	30.6	5.5	0	142	66	10	107
MC3GBR	34.4	31.1	28.3	31.3	30.9	5.3	0	144	66	4	110
Kirinda											
KC1GLR	31.7	28.6	26.1	29.3	27.7	5.3	0	80	66	78	45
KC1GBR	32.3	29.0	26.3	29.7	28.1	5.2	0	93	66	64	53
KC2GLR	31.5	28.9	26.5	29.6	28.1	4.8	0	93	66	65	55
KC2GBR	32.8	29.2	26.5	30.2	28.1	6.0	0	92	66	63	58
KC2K	34.4	29.1	26.3	30.1	28.0	7.6	0	93	66	64	60
KC3GLR	32.8	29.1	26.2	30.2	27.9	6.1	0	91	66	69	58
KC3GBR	33.2	29.7	26.7	30.7	28.5	6.1	0	107	66	53	70

Note: Adaptive graphs prepared for light blue highlighted once due variations found in the numbers. Hobo locations in each house are indicated in the table as follows: BC1GDR=Boosa Case 1 Ground Floor Dining Room/ BC1UBR=Boosa Case 1 Upper floor Bedroom etc.

Tables 4.3 and 4.4 shows the same information but averaged according to the type of rooms where the measurements were taken (Bed Room or 'Other Room' – which includes Living/Dining/Kitchen). While Table 4.3 shows the average 'comfortbale' hours Table 4.4 is indicative of average 'uncomfortable' hours during the 7 day (168 hrs) monitoring period.

Table 4.3: No. of 'Comfortable' hours in case study houses

	Boosa	Dadella	Madihe	Kirinda
Bed Room 1	49.00	15.00	6.00	64.00
Bed Room 2	85.00	12.00	48.00	63.00
Bed Room 3	53.00	53.00	4.00	53.00
Living / Dining 1	12.00	30.00	8.00	78.00
Living / Dining 2	54.00	0.00	36.00	65.00
Living / Dining 3	52.00		40.00	64.00
Living / Dining 4			10.00	69.00
Average Bed Room	**62.33**	**26.67**	**19.33**	**60.00**
Average 'Other room'	**39.33**	**15.00**	**23.50**	**69.00**

Table 4.4: No. of 'uncomfortable' hours in case study houses

	Boosa	Dadella	Madihe	Kirinda
Bed Room 1	63.00	92.00	108.00	53.00
Bed Room 2	31.00	92.00	45.00	58.00
Bed Room 3	39.00	65.00	110.00	70.00
Living / Dining 1	50.00	42.00	109.00	45.00
Living / Dining 2	35.00	73.00	58.00	55.00
Living / Dining 3	64.00		48.00	60.00
Living / Dining 4			107.00	58.00
Average Bed Room	**44.33**	**83.00**	**87.67**	**60.33**
Average 'Other room'	**49.67**	**57.50**	**80.50**	**54.50**

It appears houses at the Boosa and Kirinda sites have the highest number of 'comfortable' (i.e. below ASHRAE 55:23004 90% comfortable limit) hours while Boosa also has the lowest 'uncomfortable' (i.e. above ASHRAE 55:2004 80% comfortable limit). Houses at Madihe had the lowest number of 'comfortable' as well as the highest number of 'uncomfortable' hours. A likely explanation is the construction materials of the roof. Case study buildings at Madihe have RCC slab roof while all others have clay tile roofs on timber frames. The importance of roof to thermal comfort is also seen in a comparison of comfortable hours in the upper vs ground floors (see Table 4.2). It is generally the case that upper floor rooms were less comfortable than the ground floor. This is in line with prior studies (cf. Emmanuel, 2002) that highlighted the importance of roofs to thermal loading, given the high solar azimuth angles in the tropics.

In comparison Boosa units are two storey and create significant differences in spaces stacked above each other, with the ground floor being more comfortable. Further, the use of an insulated panel as walls as against the brick walls in Madihe is deemed to have a positive effect.

The Kirinda units are single storey, yet utilise terracotta tile roofs, thicker walls of compressed earth bricks and timber partitions bode well for the thermal comfort within spaces compared. Better cross ventilation opportunities are also a factor.

4.2 Deviations from the average

Figures 1-5 present some interesting variations found within the case study houses. The following discussions highlight some interesting findings:

Boosa – BC2GDR is more comfortable than BC2UBR

As highlighted in the preceding section, the differences between the two spaces are primarily caused by the fact that they are on two different floors of a two storey unit. The influence of the roof on the upper floor space is significant, although roof eaves and shading devices are employed, the placement is not as effective, due to the space for ventilation employed above the windows and thus the dimensions of the projections are deemed in-sufficient.

Quantum and orientation of fenestrations also deemed to play a significant role. The upper floor bed room has windows on two walls that are south and west facing in comparison to the ground floor dining room, where it has one window that faces west. Further, though stacked above each other in plan the dining space is insulated by an intermediate space on the south façade, restricting direct heat gain through the external envelope.

Boosa – BC1UBR and BC4SLR have high diurnal variations compared to others spaces studied

The comparison of upper floor bed rooms (UBR) shows that the orientation and zoning of the spaces are significant. BC1UBR has external facades that face west and south, as opposed to BC2UBR (north and west), BC3UBR (south and east). The increased diurnal range in BC1UBR is driven by the increased heat gained (Maximum temperature) through the unfavourably oriented building envelope.

BC4SLR is a single storey option. Therefore, it is devoid of the influence of the upper storey. The living room has facades facing east and south. The south façade is well shaded by a verandah. The heat gain through the roof and east façade is significant during the morning hours. The influence diminishes to the latter part of the day when the western sun has little or no influence on the space due to zoning within the house.

Dadella – DC3UBR is relatively more comfortable than other spaces in Dadella

DC3 is a prime example of the influence of the context can have on the indoor thermal comfort of a development. DC3 in comparison to other houses in the development abuts a wider street (the main access road) as opposed to the other cases that are situated alongside internal roads in the housing estate. This factor contributes to the better access to site ventilation. The layout of the unit is conducive for cross ventilation, and in particular has less occupants, less furniture creating a more open interior, thus positively affected by the increased ventilation opportunity. The floor level of the house is also lower than that of the road, therefore offers a degree of shelter from reflected radiation from the road surface.

Madihe – Diurnal range MC2GBR is low compared to MC3GBR, however MC2GBR appears to be more comfortable

MC2 is unique in comparison, such that the unit has a verandah structure on the western façade. This metal roofed, open structure is used as workshop. In units that have little no shade for the building envelope, the verandah creates an external shading structure for the walls and fenestration, thus reduced solar heat gain into the interior. Further, the presence of significant trees in close proximity adds to the external shading of the building envelope.

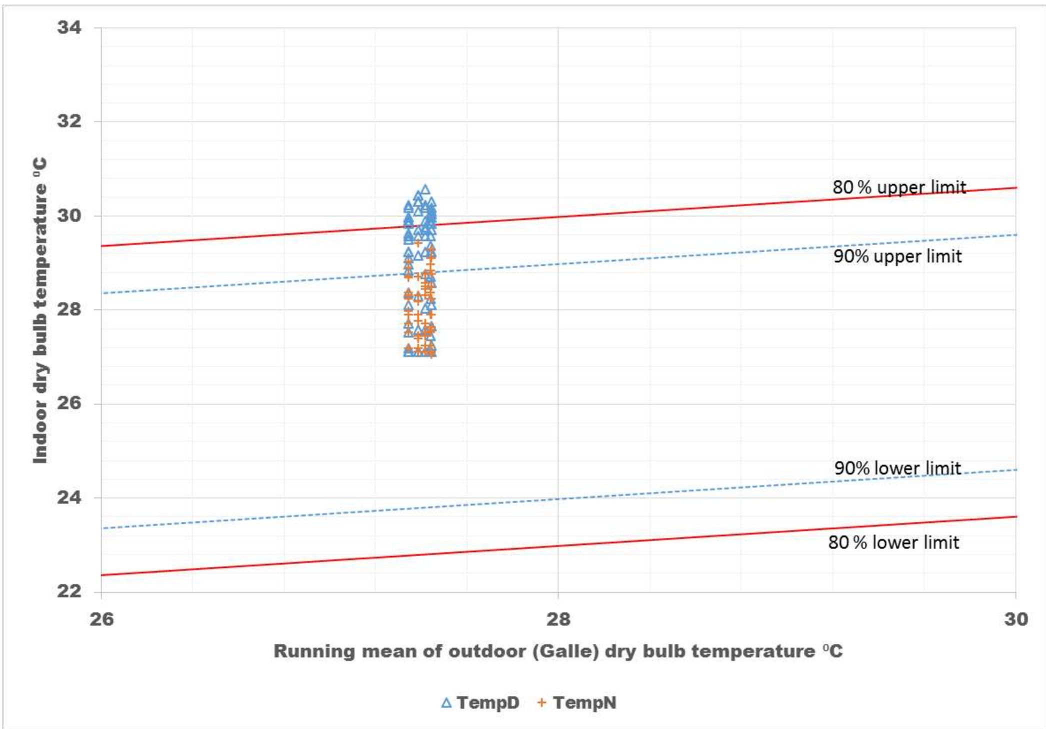


Fig. 1: Internal temperatures of BC2GBR compared to ASHARAE-55 90% and 80% acceptability limits

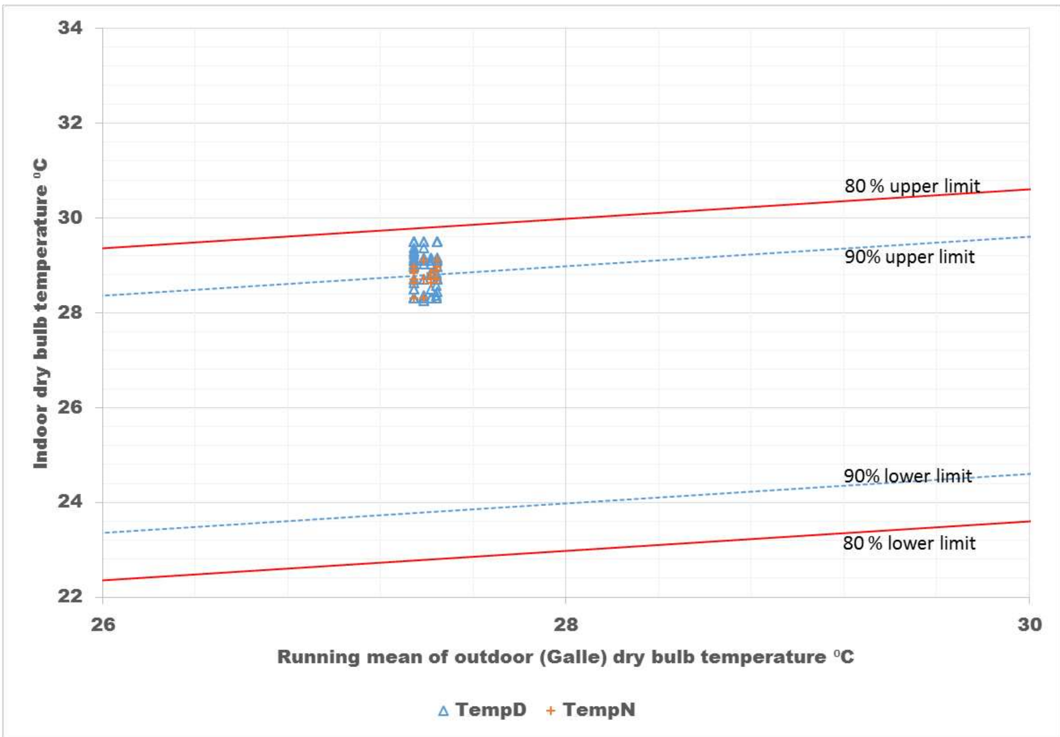


Fig. 2: Internal temperatures of BC3GDR compared to ASHARAE-55 90% and 80% acceptability limits

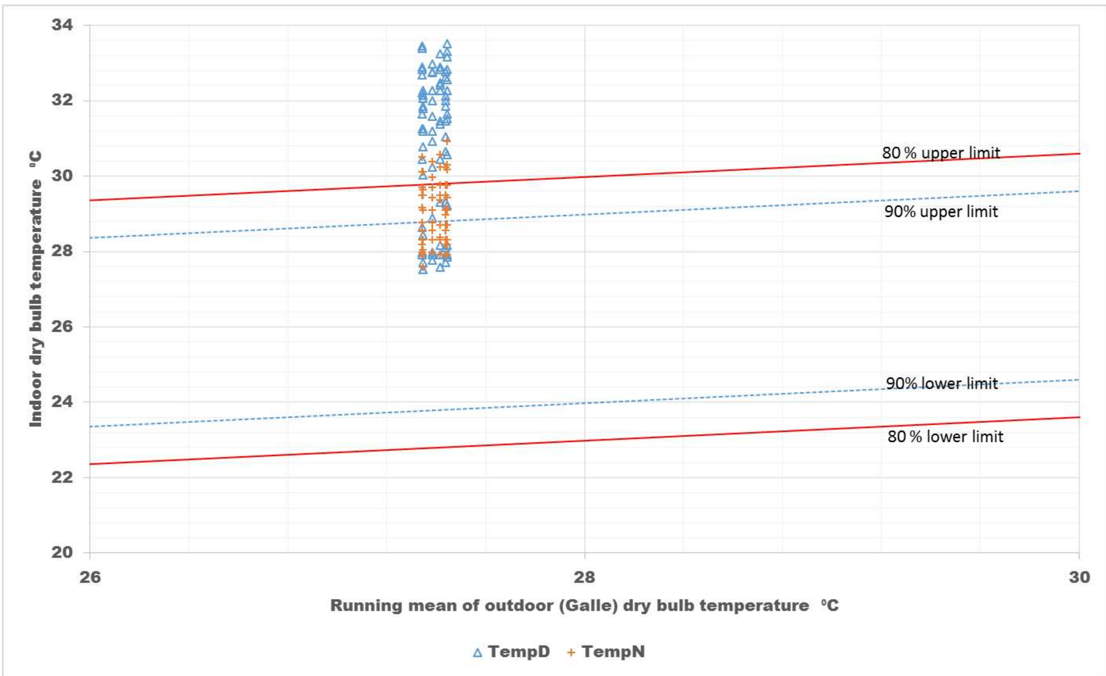


Fig. 3: Internal temperatures of DC3UBR compared to ASHARAE-55 90% and 80% acceptability limits

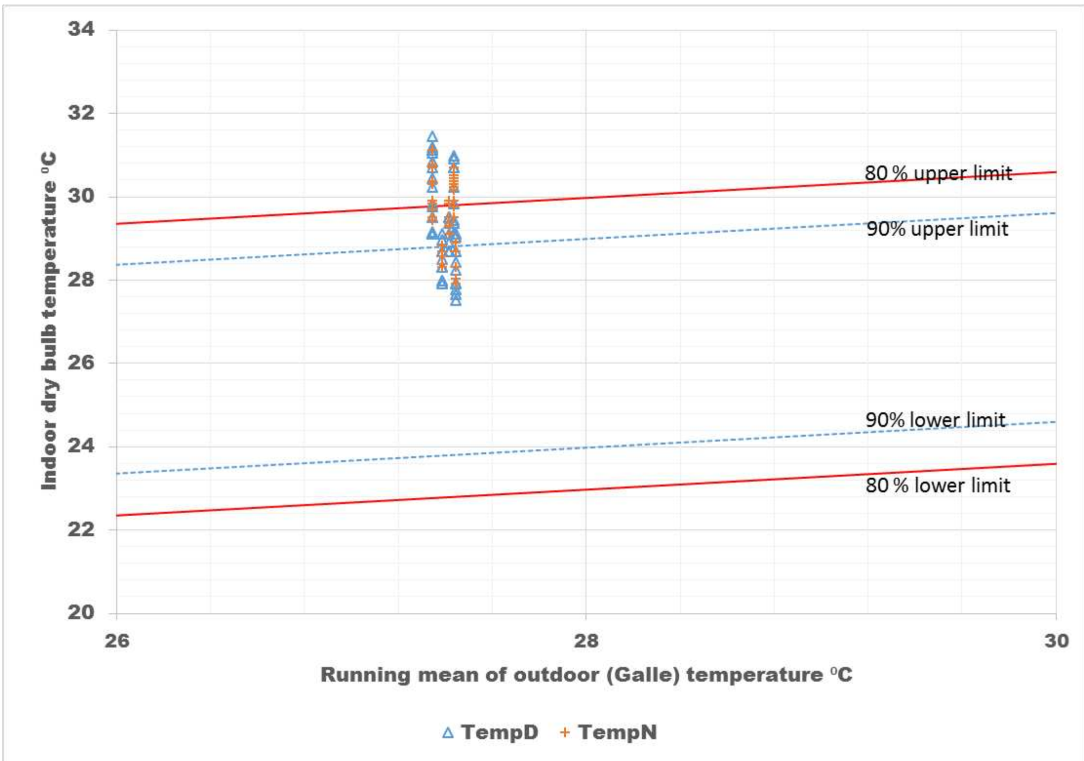


Fig. 4: Internal temperatures of MC2GBR compared to ASHARAE-55 90% and 80% acceptability limits

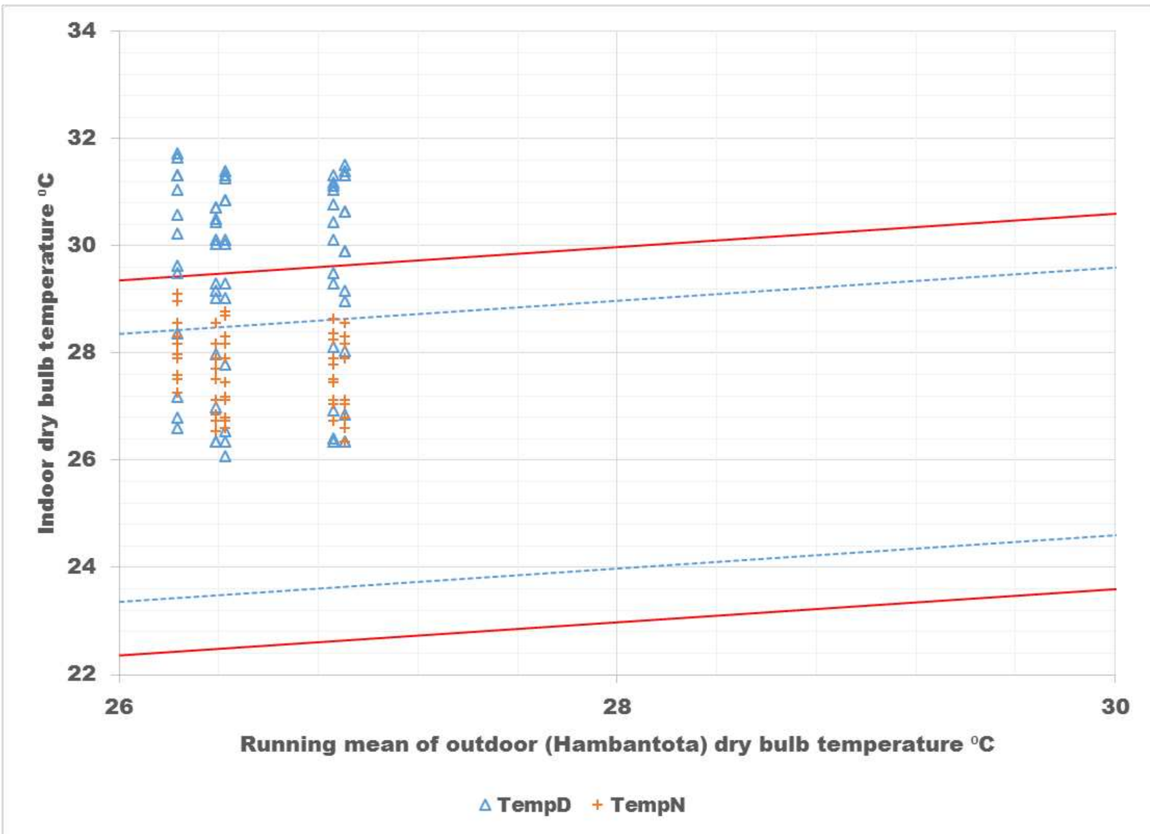


Fig. 5: Internal temperatures of KC1GLR compared to ASHARAE-55 90% and 80% acceptability limits

4.3 The role of context

The role of the context was shown to be significant in the case studies that were discussed in the preceding section. Building siting and orientation effects were seen to impact in terms of both solar heat gain reduction (Boosa – see figures 6, 7, 8 and Madihe – see figures 9 & 10) and ventilation enhancement (Dadella – see figure 11). External structures and vegetation was a positive impact for the Madihe case study (see figure 11).

Fig 6: Boosa Case 1 – Fisheye camera images – Outdoor Context

Fig 7: Boosa Case 2 – Fisheye camera images – Outdoor Context

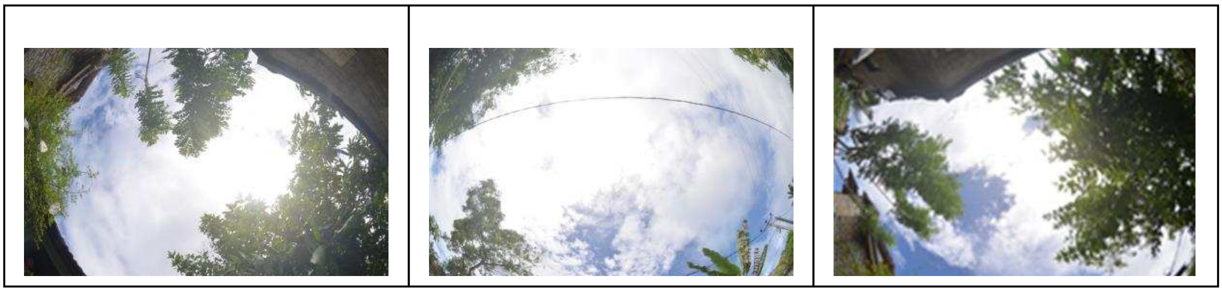


Fig 8: Boosa Case 4 – Fisheye camera images – Outdoor Context

Fig 9: Madihe Case 2 – Fisheye camera images – Outdoor Context

Fig 10: Madihe Case 3 – Fisheye camera images – Outdoor Context

Fig 11: Dadella Case 3 – Fisheye camera images – Outdoor Context

5. IMPLICATIONS AND CONCLUSIONS

Summary of findings

Comparative analysis of case study confirms much of the established knowledge for building in the warm, humid tropics, both in the neighbourhood scale and the building scale.

At the neighbourhood scale:

- Context and orientation was seen to have a significant effect on the indoor thermal comfort condition. (See Boosa, Dadella, Kirinda)
- External shading provision from built structures (Madihe) and vegetation (Madihe) was significant.

At the building scale:

- Zoning of habitable spaces had an impact on the comfort patterns of individual spaces. (Boosa, Kirinda)
- Material selection and insulation of the building envelope is important (Boosa, Kirinda)
- Optimum provision for ventilation is key (Dadella, Kirinda)
- Roof form and material was shown to be a critical aspect of building in the tropics (Madihe – flat roof vs. terracotta tiled angled roofs for other developments)

Implications for design

The post disaster housing developments faced the conundrum of mass scale building programmes within a limited time frame. The lack of proper building codes and legal enforcement frameworks for both the design and building stage did not bode well for the overall quality of housing.

Future guidelines need to start at the neighbourhood level. It is pertinent for any mitigation or adaptation strategies to encompass approaches to reducing the microclimatic effects in the outdoors. These approaches - enhanced shade, ventilation, increased albedo and included vegetation - form the basis for such a protocol.

The study highlighted the importance of the building envelope in achieving thermal comfort. An emphasis on design guidelines that are focused on controlling the negative effects of the microclimate into the interior habitable spaces is key. Orientation; materiality; scale, placement and shading of fenestration as a part of the building envelope needs prescriptive thresholds for their inclusion in any guidelines developed.

Overall, an approach to creating meaningful and people centered spaces within a housing development that is burdened with many constraints need to encompass simple yet effective strategies that embrace a holistic overview from the context right down to the choosing of materials.

5.1 Directions for further study

The present study is limited due to time and resource constraints to a few case studies, although these are representative of the many post-tsunami 2004 housing in Southern Sri Lanka. It is now necessary to carry our further studies to confirm or dispute the present findings as well as to further develop practical design guidelines for post-disaster housing to be 'build back better.' Before this could be attempted the following areas need particular attention:

Model passive improvements to minimise the overheating and discuss the overall impact in the context of Tsunami housing in Sri Lanka;

Assess the actual thermal state and preferences of occupants to verify findings based on comfort standards;

Explore the actual thermal adaptation actions of occupants, with the aim of better understanding the usability and overall thermal performance of the houses.

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7. AUTHORS CONTRIBUTIONS

The different expertise of each author of this paper has contributed substantially to its development. Prof R. Emmanuel contributed as the chief advisor and directed the structure, objectives, data collection and writing of the paper. Dr R. Giridharan contributed to the research objectives, data analysis and interpretations of findings. Dr. N. G. R Perera and Dr. S. B. A Coorey contributed to literature review, data collection and interpretations of findings and drafting of final report.

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ANNEXURES

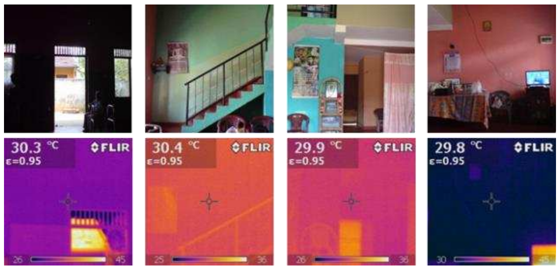
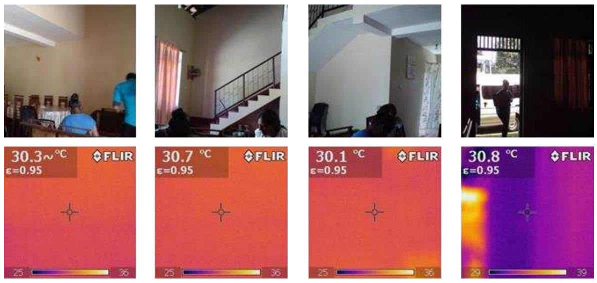
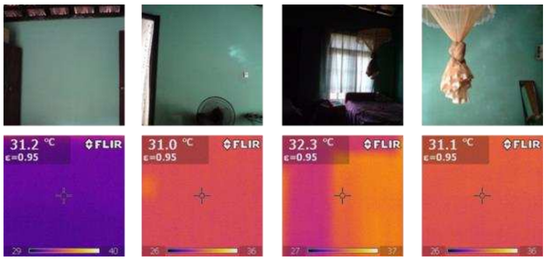
Annexure 1

Thermal Camera Images - Boosa

Case	Living room	Bedroom
Boosa Case 1		
Boosa Case 2		
Boosa Case 3		
Boosa Case 4		

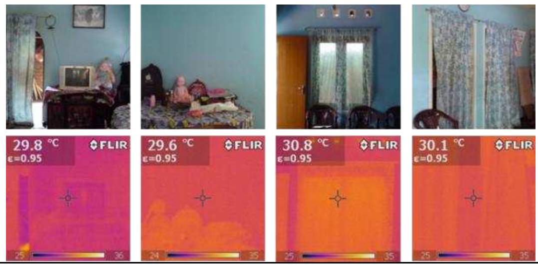
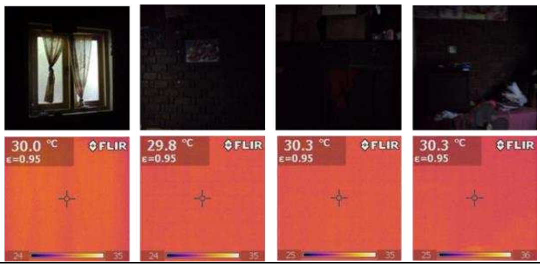
Annexure 2

Thermal Camera Images - Dadella

Case	Living room	Bedroom
Dadella Case 1		
Dadella Case 2	 	
Dadella Case 3		

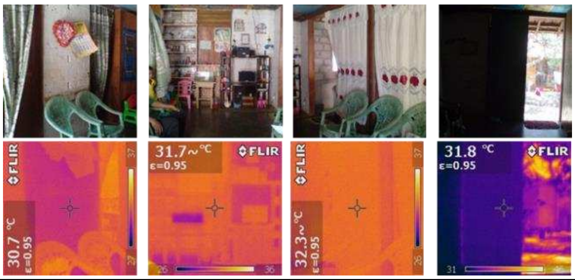
Annexure 3

Thermal Camera Images - Madihe

Case	Living room	Bedroom
Madihe Case 1		
Madihe Case 2		
Madihe Case 3		

Annexure 4

Thermal Camera Images - Kirinda

Case	Living room	Bedroom
Kirinda Case 1		
Kirinda Case 2		
Kirinda Case 3