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Daylighting Strategies in Tropical Coastal Area

A Lesson From Vernacular Houses

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Abstract: The provision of daylighting within a building performs an essential function, not only for health and visual comfort but also for energy efficiency in lighting. In tropical areas, however, excessive sunlight radiation and intensity have become a common problem in providing a sufficient amount of daylight, because they can lead to overheating. Several daylighting strategies are often employed by vernacular houses to provide daylight and to avoid heat radiation and glare. These strategies often use ray-ban glass windows material, as well as external and internal shading devices. This paper aims to investigate daylighting strategies in tropical coastal vernacular buildings and their potential application for improving daylighting performance in modern houses in the same climate.

The daylight performance of three houses in a tropical coastal area was investigated via field study. The samples were chosen purposively based on construction, building material, building height and window material. Outdoor and indoor light illuminance were measured simultaneously. Indoor measurement points were placed at a height of 0.7 meter above the floor level, with 1-meter space grids. The daylight factor and illuminance level were used as performance indicators.

The results indicate that the sampled houses perform poorly in regard to daylighting. This condition was caused by factors such as small-sized windows, the use of Ray-ban glass combined with the use of curtains that blocked almost 30% of daylight. Better daylighting conditions were observed in rooms with large openings (20%–40%).

1. INTRODUCTION

Energy demand has rapidly been increasing in recent decades. Buildings are a growing sector for energy consumption, accounting for about 30%–40% of all energy consumption (Cemesova, Hopfe, & McLeod, 2015; Pérez-Lombard, Ortiz, & Pout, 2008; Wang, Gwilliam, & Jones, 2009). Therefore, reducing energy consumption and using it in an efficient manner has been the main objective for many researchers in recent years (Hui, 2001; Rosselló-Busquet & Soler, 2011; Tagliabue, Buzzetti, & Arosio, 2012). One factor that increases energy use in buildings is artificial light. Indeed, it is reported to comprise 19% of electricity use worldwide (International Energy Agency (IEA), 2006). Therefore, the use of natural daylight has been promoted globally for use in buildings, specifically to improve health and visual comfort (Das & Paul, 2015; Galatioto & Beccali, 2016) as well as energy efficiency (Acosta, Campano, & Molina, 2016; Li et al., 2006).

Tropical climates are mainly characterized by direct sunlight, as well as diffuse lighting from occasional cloud cover. Overall, sky brightness is higher and seasons are less variable (Baker, 1987). Tropical climates are also marked by long sunshine hours, making it possible to improve energy efficiency through daylighting. In these areas, however, strong solar radiation is a possible outcome of daylight, which can result in overheating. Hence, an increase in light performance might lead a decrease in thermal performance if the daylighting strategies employed are not suitable (Gago et al., 2015). This paper compares the daylighting performance of several residential buildings in a tropical coastal area, and further analysed the suitable strategies for optimal daylighting performance.

Daylight is defined as a combination of sunlight and diffused light from the sky. Daylight penetrates into buildings from various openings placed throughout, and is influenced by direct sunlight, sky components (diffuse skylight), external reflection components (reflected light by ground or obstructions), and internal reflection components (walls, floor, ceiling and other internal surfaces) (Das & Paul, 2015). Several strategies have been implemented to maximize daylighting performance by form and location of opening (Acosta, Campano, & Molina, 2016; Ghisi & Tinker, 2005; Huang & Wu, 2014), such as a light-shelf (Freewan, 2010; Freewan, Shao, & Riffat, 2008; Lim & Heng, 2016), a light-pipe (Chirarattananon, Chedsiri, & Liu, 2000), shading (Freewan, Shao, & Riffat, 2009; Gugliermetti & Bisegna, 2006; Konstantoglou & Tsangrassoulis, 2016; Konstantzos & Tzempelikos, 2016) and interior reflectance (Acosta, Campano, & Molina, 2016; Mangkuto, Rohmah, & Asri, 2016). However, the implementation of all daylight strategies, especially in a residential building, is not an easy task; There are several practical and economic issues. Therefore, daylight strategies employed in a domestic building should be: 1) easy to implement and 2) economically efficient.

In tropical coastal areas, a strong direct solar radiation is dominant. Furthermore, the existence of the sea can potentially make over-illumination and glare from the external environment more serious issues. Vernacular architecture has its own solutions to adapt to the outside environment, including a luminous environment. Therefore, before presenting suitable daylighting strategies for tropical coastal areas, this study first investigates daylighting strategies used in tropical coastal vernacular buildings. This paper provides recommendations for daylighting design strategies in residential buildings, especially in tropical coastal areas.

2. METHOD

2.1 Case study

The study area is located in a tropical coastal area in Labuan Bajo Donggala, Sulawesi Tengah, Indonesia (Figure 1), which is situated in 00°39’37.3”-00°39’37.3” South, and 119°44’17.6”–119°44’31.9” East. The area is characterized by abundant sunlight, high solar radiation, and partially cloudy skies. Indoor temperatures can reach 33.2ºC in the afternoon. Thus, design openings for daylighting should be carefully calculated.

Figure 1. Location of the Study Case

2.2 Lighting measurement

A field study was conducted to investigate lighting performance in three different house types in the area. Light was measured simultaneously outdoors and indoors using Mastech MS6612 (accuracy: 0,03). The point of measurement inside the house was determined by a 1m x 1m horizontal grid, and a 0.7m vertical grid. Thus, the daylight contour can be mapped on the work plane level (Figure 2).

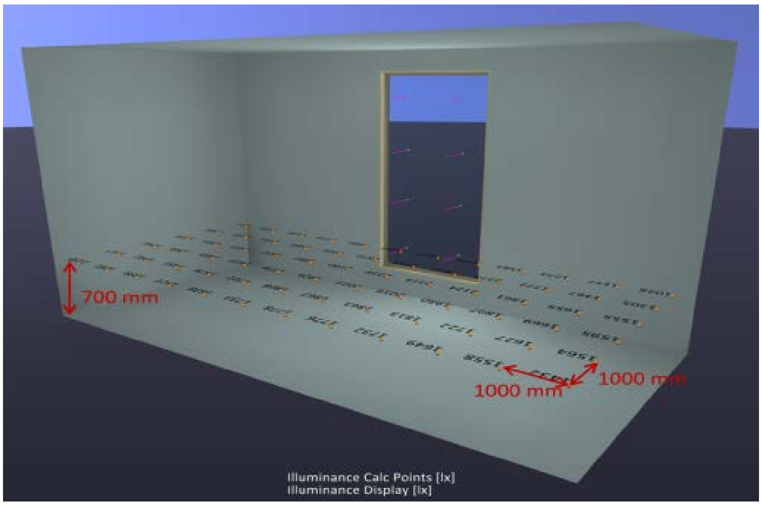
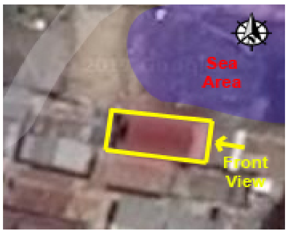
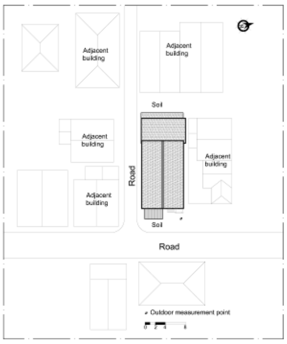
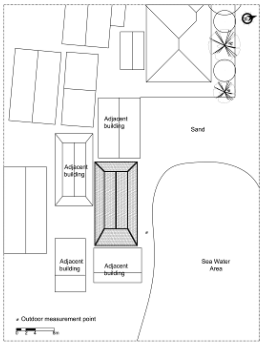
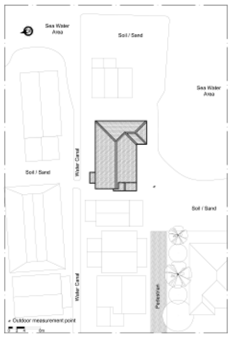
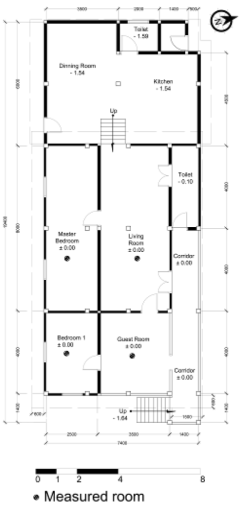
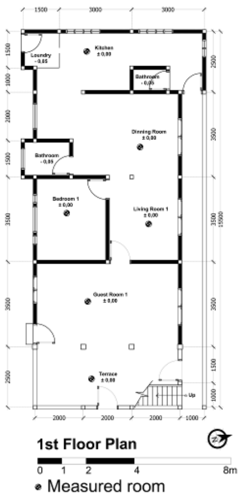
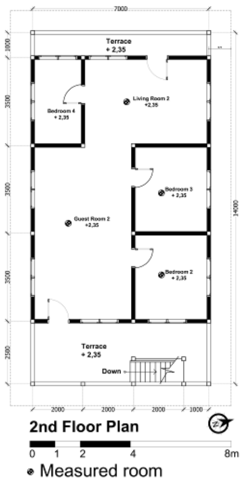
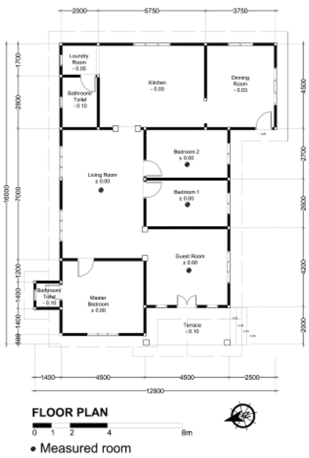


Figure 2. Method of Daylighting Measurement

2.3 Sample houses

The sampled houses were chosen purposively by considering several variables, including distance from the sea, construction and material, height, and window material. A description of the houses is provided in Tables 1 and 2. Sample 1 and Sample 2 present vernacular construction, while Sample 3 presents modern construction in the case study area.

Table 1. Sample Houses Location, Plan, and View

	Sample 1	Sample 2	Sample 3
Building Location (by courtesy of Google Map 2017, data accessed on April 17th, 2017)	 Latitude: 0.662523 S Longitude: 119.739609 E	 Latitude: 0.662557 S Longitude: 119.740233 E	 Latitude: 0.662235 S Longitude: 119.740264 E
Site Plan			
Floor Plan		 	

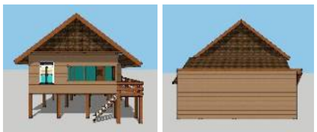
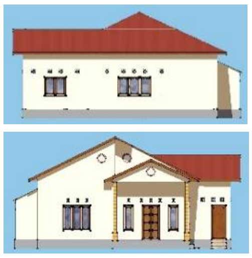
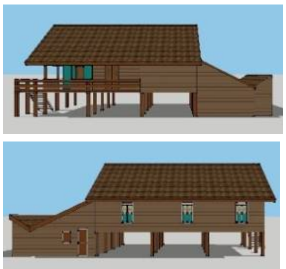
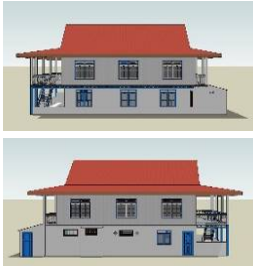
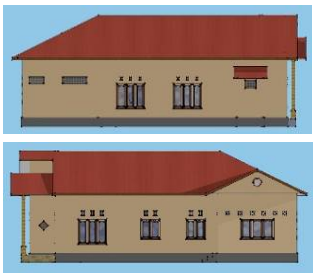
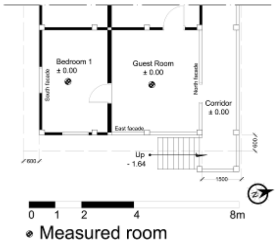
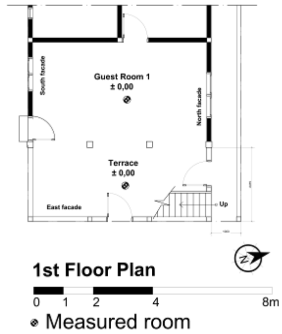
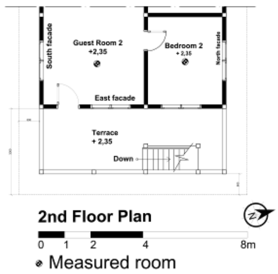
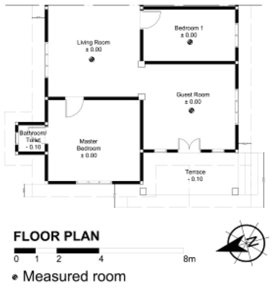
East and West View			
North and South View			
Perspective			

Table 2. Description of the Room in the Sample Houses

Design Parameter	Sample 1	Sample 2	Sample 3
Orientation	East-West	East-West	East-West
Construction and dimension	Raised floor construction house, 19.4m length, 7.4m width, and area of 134m².	Two-story house: 15.5m length, 7m width, and area of 98.97m².	One-story house: 16m length, 12,9m width, and area of 163m².
Building materials	Floor and walls: light-blue painted wood board. Ceiling: light-blue painted bamboo mat Roof: sago thatch roof.	**1st floor:** cream-coloured reflective ceramic tile flooring, white plaster brick walls, and white ceiling **2nd floor:** light-brown unpainted wood floor, dark-brown glossy painted walls, and white ceiling Roof: Red corrugated iron sheet	Floor: reflective cream-coloured ceramic tile Walls: orange-coloured plaster brick wall. Roof: green corrugated iron sheet
Openings	• Opening 1 placed in the guest room. Fixed opening without window panel; 750mm height from floor; 3250mm(W) x 1200mm (H) on East façade, (900mm + 1850 (W)) x 1200mm (H) on North façade, and fixed opening door without door panel 900mm (W) x 1950mm (H). • Opening 2 Wood-framed window: half wood panel and half wood jalousie; 750mm from floor; double side hung windows, 900mm (W) x 1100mm (H). Wooden horizontal bars (fixed upper ventilation opening); 200mm (H). Placed on South and East façade of bedroom 1, and 2 windows on master bedroom South facade. • Opening 3	**1st floor** • Wood-framed window with ray-band glass; 400mm from floor, 2 x 620mm (W) x 1200mm (H), and fixed glass 200mm (H) opening at upper window. One placed on north façade of each guest room, living room, and dining room. • Wood-framed window with ray-band glass; 800mm from floor, 2 x 500mm (W) x 790mm (H), placed on south façade of the guest room. • Fixed horizontal bar opening 1500mm from floor, 1000mm (W) x 300mm (H) on south façade of bedroom 1. **2nd floor** • Wood-framed window with ray-band glass; 500mm from floor, 2 x 720mm (W) x 1150mm (H), and fixed horizontal bar 260mm (H) opening at upper window, one placed on East and two on South façade of Guest room, 1 window for each of bedrooms, and 1 on North and West façade of living room.	• Wood-framed window with ray-band glass; 500mm from floor, 2 x 520mm (W) x 1450mm (H), and double panel door 1000mm (W) x 1950mm (H), placed on West façade of guest room. • Wood-framed window with ray-band glass; 500mm from floor, 3 x 520mm (W) x 1450mm (H). One unit placed on South façade of guest room, and two units placed on North façade of living room. • Wood frame window with ray-band glass; 850mm from floor, 2 x 520mm (W) x 1100mm (H), placed on both Bedroom 1 and 2.

	Wooden panel door on the living room 1000mm (W) x 1950mm (H).	• Wood panel door 800mm (W) x 1800mm (H), one placed in the guest room and one in the living room.	
External Shading Elements	Roof eaves: bedroom 600mm, guest room and living room North façade 1500mm 	Shelf-shading from 2nd floor cantilever: guest room 1 and living room 1 North façade 1000mm. Guest Room east façade 2475mm  z Roof eaves: Guest room 2 East façade 3300mm, South façade 800mm, bedroom 800mm. 	Roof eaves: Guest room West façade 2600mm, guest room and bedroom south façade 600mm, living room North façade 600mm 
Internal Shading Elements	One layered curtain covered half of the window area.	One layered curtain covered 35% of windows area on the 1st floor. One layered translucent curtain covered 100% of windows area on the 2nd floor.	One layered translucent curtain covered 100% of windows area on the West façade of guest room. A two-layer curtain: 1st layer is a translucent curtain that covered 100% of openings, and 2nd layer is a thick fabric that covered 35% of opening area.
Surrounding obstruction	Adjacent building in the North (1000mm distance) and West (3000mm distance) side of the house.	Adjacent buildings on the East (500mm distance), South (1000mm distance) and West (1000mm distance) sides of the house.	Adjacent buildings on the West (2000mm distance) and East (4000mm) sides of the house.

2.4 Daylight Performance Analysis

A daylight performance analysis was conducted by applying useful daylight illumination (UDI) and daylight factor (DF). The UDI offers potential useful illumination for building occupants when daylight illuminance ranges from 100–2000 lx (Nabil & Mardaljevic, 2006).

The daylight (DF) is the ratio of external and internal illuminance.

$$DF = E_i / E_o \times 100 \qquad (1)$$

Where E_i denotes illuminance at a point in a building's interior, and E_o denotes illuminance at a point in an unobstructed external environment.

3. RESULT AND DISCUSSION

3.1 Daylight Condition of the Sampled Houses

3.1.1 Detailed illuminance environments in sample 1

The daylighting condition in sample 1 exhibited a low illuminance level ranging between 4–157 lux. However, the guest room area was sufficiently illuminated, with an illuminance level ranging between 240–1530 lux and an average daylight factor (DF) of 1.0 (Figure 3). This condition was created by large openings, and an opening to wall area ratio of 48% (Figure 4). Moreover, the openings are placed on two sides and are perpendicular to each other; The openings to floor area ratio (OFR) is 68%.

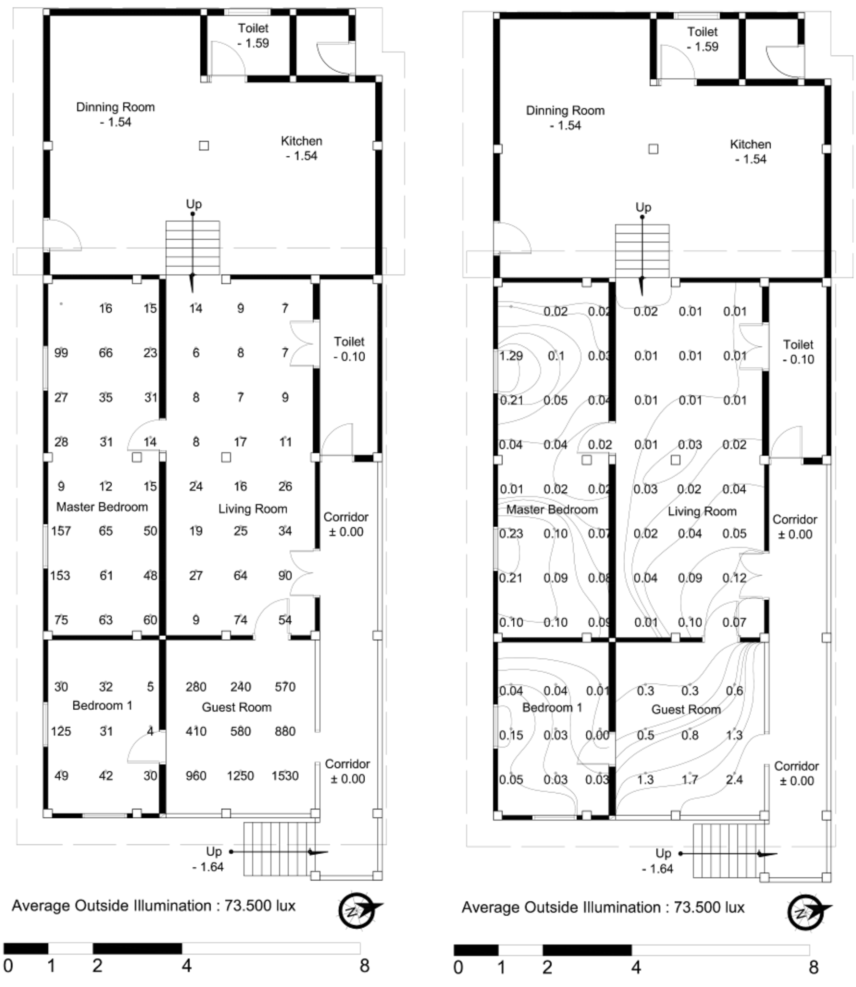


Figure 3. Illuminance Level (in lux) and Daylight Factor Contour of Sample 1

Conversely, daylighting conditions in the living room were low, with an average daylight factor of 0.03 (Figure 3). Regardless of outdoor illuminance, which varied between 62,100–104,500 lux, the lighting in this room only varied between 6–90 lux. The available outdoor illuminances were intended to provide sufficient daylighting to indoor spaces, unless the room has a small opening area such as in this case. The opening area in the living room was only 12% of both the OWR and OFR. The openings in the living room are doors made from wood. Consequently, they cannot function as a light opening when the door's pane is closed (Figure 4). Most of the time, one door remained closed, making the living room even darker. As a result, electric lights were used even during the day due to a lack of light.

Figure 4. Openings in Guest Room and Living Room of Sample 1

The lighting conditions in both bedrooms of sample 1 were considered low, with a maximum daylight factor of 0.15 for bedroom 1 and 1.29 for the master bedroom. The average daylight factor for both rooms was 0.04 and 0.13, respectively. These values are lower than the minimum daylight factor requirement for bedrooms, which is 0.5.

Lighting illuminance in bedroom 1 ranged between 4–125 lux, with an average illumination of 39 lux. Similarly, the lighting illuminance in bedroom 2 (master bedroom) varied from 9–157 lux, with an average of 50 lux. The size of the openings in both bedrooms are considered small, since the OWR and OFR for bedroom 1 are only 12% and 20%, respectively, and for the master bedroom the ratio of both is only 10%. Useful lighting illuminance was only achieved in the areas closer to the openings (i.e. 0.5–1 meter), while rest of the area had insufficient lighting.

The windows are made from wood. Consequently, the sunlight cannot pass through the room when the windows are closed. When the windows are open, however, the daylight that penetrated into the room was reduced by more than 50% due to the use of a curtain that covered 60% of the windows area (Figure 5). This condition worsened the light conditions in the bedroom.

Figure 5. Opening in Bedroom of Sample 1

3.1.2 Detailed illuminance environments in sample 2

The daylighting condition in sample 2 is quite similar to the previous one. However, higher illuminance and a greater daylight factor can be observed in the guest rooms, both on the first floor and the second floor. The average daylight factor in the guest room on the first floor is 0.9, and it is 3.2 on the second floor (Figure 7). The illuminance value ranged between 60–1440 lux on the first floor and 75–1890 lux in the second floor (Figure 6).

Figure 6. Illuminance Level on (in lux) of Sample 2

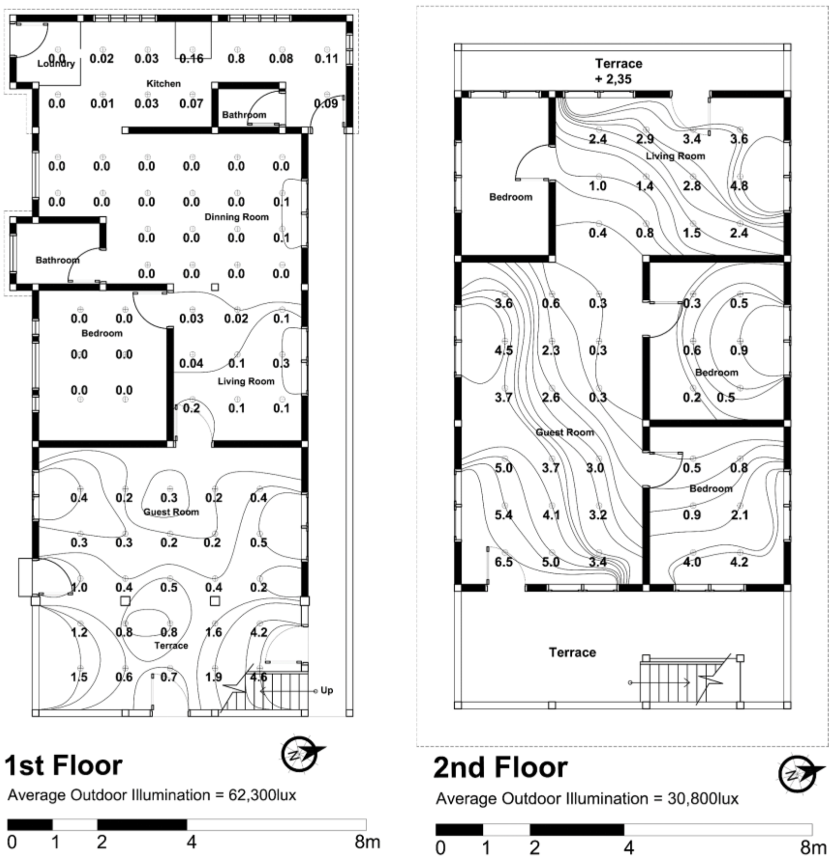


Figure 7. Daylight Factor Contour of Sample 2

The better lighting performance in both guest rooms was the result of a large OWR, which was 43% on the first floor and 28% on the second floor (Figure 8). Moreover, the OFR in these rooms was 33% on the first floor and 22% on the second floor, both of which were larger compared to other rooms. Additionally, the openings were placed on two sides of the walls that are parallel in the first floor and perpendicular in the second floor.

Figure 8. Opening in the Guest Rooms of Sample 2

Both guest rooms had high reflectance ceilings (white painted LRV = 85%). Although the first-floor walls were painted a lighter colour (white painted) than the second floor (brown painted), the second-floor walls had glossy surfaces that reflected some of the light coming into the room.

Unlike in the guest room, the light condition in the living rooms were completely different between the first and second floors. The average lighting level on the first floor of the living room was 44 lux, while on the second floor it was 714 lux. The average values for the daylight factors were 0.1 on the first floor and 2.3 on the second floor. The opening ratio in the living room on the second floor was larger than in the living room on the first floor: the OWR was 12% and 17%, for the first floor and second floor respectively, and the OFR was 31% and 33%, respectively as well. Beside different opening sizes, the windows also differed in regard to curtain use. The curtain on the window in the living room on the first floor covered 35% of the opening area, reducing the amount of light that passed through the windows (Figure 9).

Figure 9. Opening in the Living Rooms of Sample 2

Curtain use also reduced the amount of light in the dining room (Figure 10). Indeed, light penetration through the windows was reduced by 30–35%. The average lighting level in this room was 18 lux, which is far below the useful daylight illumination standard of 100 lux. On the contrary, the average outdoor illumination was 71.470 lux, which had the potential of providing natural illuminance. Low levels of illuminance in this room were also mainly caused by insufficient opening size (OWR 17% and OFR 9%).

Figure 10. Opening in the Dining Room and Kitchen of Sample 2

Figure 11. Opening in the Bedrooms of Sample 2

Similar to the living room, the lighting conditions in the bedrooms differed significant from the first floor to the second floor. The bedroom on the first floor lacked light (2–3 lux) due to a small light opening (OWR of 4% and OFR of 3%) and an obstruction from the adjacent building. In contrast, the second-floor bedrooms had wide openings (bedroom 2 has OWR of 26% and OFR of 40%, and bedroom 3 has OWR of 28% and OFR of 20%). Daylight illuminance ranged between 151–1230 lux in bedroom 2 and between 72–288 lux in bedroom 3, which were sufficient in providing natural lighting.

Interestingly, daylighting strategies were also found in the kitchen. Top-lighting can provide daylight in tropical warm climates in a way that reduces heat gain. The skylight was used to overcome low lighting possibility due to an obstruction caused by an adjacent building in the side-openings (South and West side of the house). Even though the lighting level was below standard, top-lighting improved the illuminance in the kitchen compared to bedroom 1. While the opening size in the kitchen was almost the same as in bedroom 1 (OWR of 3% and OFR of 4%), the illuminance level was 20 times higher than in bedroom 1 (average illuminance was 2 lux in bedroom 1 and 55 lux in the kitchen).

3.1.3 Detailed illuminance environments in sample 3

Lighting strategies in sample 3 are similar to those in the vernacular houses. Hence, illuminance conditions in this house did not differ much from previous ones: The brightest room was the guest room, with an average daylight factor of 1.4 and an average illuminance of 645 lux. The illuminance level in the other rooms was very low. The average daylight factor was only 0.3 and the average illuminance varied from 74 lux–111 lux. The measured range of illuminance in all rooms was 123–270 lux, 23–491 lux, 27–195 lux and 39–355 lux for the guest room, living room, bedroom 1 and bedroom 2, respectively (Figure 12).

Opening size in the sample 3 guest room had an OWR of 18% and OFR of 30%, while the living room had an OWR of 18% and OFR of 14%. Openings in both bedrooms had an OWR of 12% and OFR of 10%. For better daylighting performance, the recommended opening size is at least

20% of the wall area. Thus, the guest room should indeed have better daylighting performance than the other rooms.

Similar to previous samples, extensive curtain use reduces illuminance in the interior of the house. Curtains block most of the daylight that comes through window glass. Ray-band glass is used to overcome the glare issue. This material reduces the amount of daylight before it even reaches the curtain, thereby the amount of light is doubly reduced.

Figure 12. Illuminance Level and Daylight Factor Contour of Sample 3

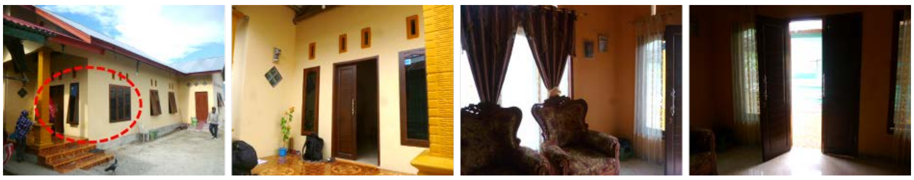


Figure 13. Opening in Guest Room of Sample 3

Figure 14. Opening in the Living Room and in the Bedrooms of Sample 3

3.2 Daylighting Performance of the Sample Houses

Daylighting performance was assessed using useful daylight illuminance (UDI) and daylight factor (DF) as a percentage of the recommended standard in the work plane of the room area. Useful daylight illuminance in this study was determined from 100–2000 lux (Nabil & Mardaljevic, 2006), while the DF standard was modified from the Building Research Establishment (BRE) recommendation in residential buildings (Table 3).

The BRE standard was modified to suit the conditions in tropical areas, where outdoor illumination is higher than in the northern or southern hemispheres. The DF used in this study was based on an illuminance level of 100–300 lux that could only be achieved by a DF of 0.5. As an additional consideration, the average value of the total DF and illuminance level for a given room were used to determine the best performing room.

Table 3. Modified DF_{ave} BRE Standard Used in Analysis

Room	BRE DF_{ave}	Recommendation	DF_{ave} Modified
Living Room	1.5%	Minimum 50% of floor area	1.0%
Kitchen	2.0%	Minimum 50% of floor area	2.0%
Bedroom	1.0%	Minimum 70% of floor area	0.5%

Of the 17 rooms from three sample houses that were measured, 7 rooms exhibited good daylighting performance. The best daylighting performance was observed in sample 2, in which 55% of the measured room (5 rooms out of 9) was sufficiently lit. In other samples, only 25% of the measured rooms received enough daylight (Table 4). The best performing room was bedroom 2 of sample 2. This room achieved sufficient illuminance from daylight for 100% of the room area, according to both the UDI standard and DF standard. The second-best daylighting performance was achieved by the second-floor living room of sample 2: 100% of its area achieved useful daylight illuminance, and 83% of the area satisfied the DF standard for living room.

Table 4. Daylighting Performance of Sample Houses

No	Sample	Room	OWR	OFR	UDI %	DF%	Ave DF	Ave Illuminance
1	Sample 1	1 GR	48	64	100	70	1.00	744
2		1 LV	10	7	0	0	0.03	24
3		1 BD1	12	20	11	0	0.04	39
4		1 BD2	10	10	9	4	0.13	50
5	Sample 2	2 GR 1	43	33	92	28	0.90	375
6		2 GR 2	28	22	89	78	3.20	997
7		2 LV 1	12	17	11	0	0.10	59
8		2 LV 2	27	33	100	83	2.30	714
9		2 DR	17	9	5	0	0.02	18
10		2 BD1	4	3	0	0	0.01	3
11		2 BD2	26	40	100	100	2.10	619
12		2 BD3	28	20	67	67	0.50	144
13		2 KC	3	4	17	0	0.06	55
14	Sample 3	3 GR	19	30	100	56	1.40	645
15		3 LV	18	14	22	11	0.20	106
16		3 BD1	13	10	22	11	0.20	74
17		3 BD2	12	10	33	11	0.30	111

Note: GR : Guest Room; BD : Bedroom
LV : Living Room; KC : Kitchen
DR : Dining Room

Other rooms that achieved adequate daylight illuminance include the guest room of sample 2, the second-floor guest room of sample 2, guest room of sample 3, the first-floor guest room of sample 2, and bedroom 3 of sample 2. All of these rooms employed similar daylight strategies related to opening size (i.e., OWR and OFR). In almost all rooms, OWR and OFR were equal to 20% or more, except for the guest room of sample 3, for which the OWR was 19%. Regardless of instances where the ratio did not reach 20% of wall area, the OFR value exceeded 20%, reaching 30%. Moreover, an OWR of 19% is quite close to 20%, so it can still be said that the guest room of sample 3 achieved good daylighting performance.

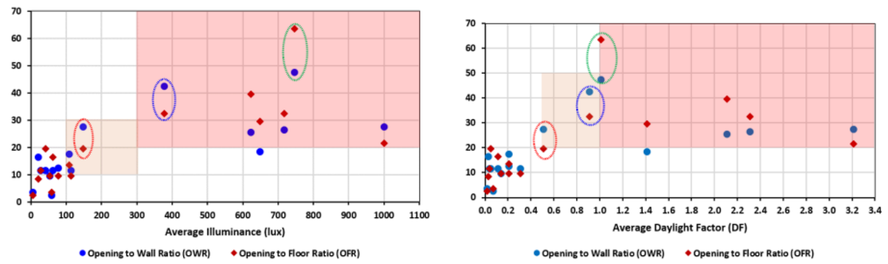


Figure 15. Opening Size vs Average Illuminance and Average DF

Figure 15 illustrates that a small size of opening (between 5%–20% OWR and OFR) cannot provide sufficient daylighting. Meanwhile, an opening size of 20%–40% ensures an illuminance level and daylight factor within the acceptable and recommended condition. An interesting phenomenon occurred when the opening-to-floor ratio was 64%: This opening only provided an average daylight factor of 1.0. This was apparently caused by an uneven distribution of illuminance, which created a large fluctuation in the level of illuminance (1530 lux and 240 lux, respectively) and daylight factors (0.3 and 2.4, respectively) in the area near the opening and the area far away from the opening. This condition created the glare problems in the evaluated room. Additionally, the perimeter area of the room was not supported by high reflectance materials. Thus, the light that penetrated from the opening could not be reflected into the depth of the room, and was therefore unable to brighten the room.

Moreover, an opening with an OFR of 22% and OWR of 28% resulted in a very high average level of illuminance (997 lux) and daylight factors (3.2), while the openings (20%–40% OFR and OWR) only achieved approximately 600–700 lux of the average illuminance, and 2.1–2.3 of the average daylight factors. This is likely due to glossy interior reflectance: The light falling on the interior surface is almost perfectly reflected, resulting in an even distribution of daylight in the room. An unobstructed external condition is also another reasonable explanation.

3.3 Summary of Daylighting Strategies in Tropical Coastal Area

The daylighting performance of each room was analysed to obtain suitable daylighting strategies for tropical coastal areas. Several design parameters were included in the analysis: opening-to-wall ratio (OWR), opening-to-floor ratio (OFR), external shading element, internal shading element, interior reflectance and opening materials. The most influential design parameter was the opening-to-floor ratio, followed by the opening-to-wall ratio. Adhering to these parameters ensured that rooms were sufficiently illuminated and achieved a more uniform daylight distribution.

The recommendations for OWR and OFR based on the study results are 20%–40%. This ratio can provide an average illuminance of between 300–

900 lux and a daylight factor from 1.0–3.2. However, the level of illuminance will be lower than 300 lux if the interior reflectance is low, especially that of the ceilings and walls. Accordingly, the use of bright colours with high reflectance is highly recommended. Moreover, the daylight factor can be lower than 1.0, even when the OWR and OFR are greater than 20%, when the obstruction from an adjacent building is high.

One major problem in a side-lit room, especially in tropical areas, is glare. The local daylighting strategies in tropical coastal areas use a jalousie window that can filter the light from glare and from direct heat gain (as in the case of sample 1). Unfortunately, this technique reduces a large amount of daylight, resulting in insufficient illumination of the interior.

A recent strategy to reduce glare involves using ray-ban glass in addition to an interior shading element, such as curtains. This element is very popular among houses in tropical climates for both protecting occupant privacy and providing aesthetic ornamentation. Unfortunately, such curtains covered almost 50% of daylight openings. The use of ray-band glass and curtains indeed reduced the amount of sunlight that penetrated into the interior of the house. Therefore, using clear glass accompanied by translucent curtain fabric (i.e. curtain vitrage) is recommended.

The use of external shading elements, such as continuous roof eaves, is required in tropical coastal area to avoid direct sunlight. External horizontal shading on the North and South walls is desirable to achieve a length that is one-third of the given wall height. In the sample houses, the length of the external shading on these walls was 0.6–0.8 meters. The East and West openings required extra protection from low circumsolar inclines, especially between 9:00 a.m. and 11:00 a.m., and 1:00 p.m. and 5:00 p.m. On these sides, the length of the external shading is recommended to be equal to the wall's height. The external shading devices in the East and West walls of the sample houses were between 2–3.3m.

A top lighting strategy can be used to overcome obstruction caused by adjacent buildings. This strategy should be carefully implemented due to heat gain issues. From the sample, top lighting can be installed in the kitchen and bathroom. The kitchen is the main source of heat gain in a house, and thus the heat gained from top lighting can be localized in the kitchen. Since the bathroom is rarely occupied, allowing for some heat gain in the bathroom is tolerable.

4. LIMITATIONS

One limitation of this study is the length of measurement used for the annual daylighting performance analysis. Moreover, the sample houses might not resemble all types of residential buildings in tropical coastal areas. In addition, field measurements cannot isolate or modify the design parameters of daylighting; Thus, the influence of design parameters such us different window materials and curtains cannot be clearly determined. Future research should focus on simulating the influence of different window materials and curtains in a tropical coastal climate.

5. CONCLUSION

This paper aimed at investigating daylighting strategies in tropical coastal buildings and their potential application for improving daylighting performance in modern houses in the same climate. The results of the study indicate that the target of better daylighting performance in a tropical coastal area was primarily the guest room. Thereby, openings were installed in two perpendicular or parallel walls in all sample houses. In contrast, the bedrooms received the least priority, because daytime activities do not often occur in the bedroom. Because occupants prefer to spend their daytime in the living room or the guest room, this might be a reason why OWR and OFR in were smaller in the bedroom.

This study confirms that the opening-to-floor ratio (OFR) and opening-to-wall ratio (OWR) are the most influential design parameters in a daylit room. The study recommends that a ratio of 20%–40% for both OFR and OWR is needed to achieve an illuminance level of 100–2000 lux and a daylight factor of more than 0.5. Several parameters that can prevent the achievement of such measurements were windows materials and extensive curtain use. The level of illuminance in the interior of a house may be improved by reducing curtain use or constructing windows entirely out of clear glass.

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