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DETERMINING INDOOR THERMAL COMFORT CONDITION OF KUTAI HOUSE THROUGH BIOCLIMATIC ANALYSIS

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ABSTRACT

Conserving the traditional Malay Kutai houses as our building heritage is important before they perish due to neglection. For maintenance purposes, the palm leave roofs are replaced with more durable materials such as zinc or onduline roof sheets. Replacing the building materials without understanding their properties could cause harmful effect on the indoor thermal comfort. Previously, there is minimal quantitative research done to prove that the traditional Malay house is thermally comfortable. Thus, this research intends to measure the thermal comfort parameters of Kutai house and analyse the result using a bioclimatic chart. The results revealed that the average thermal comfort conditions of the Kutai houses are within the boundaries of comfort zone as recommended for natural ventilated buildings despite using zinc roof.

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Keywords: *Thermal Comfort; Bioclimatic, Overall Heat Transfer Coefficient*

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INTRODUCTION

Malaysia is located at low latitudes between 0º to 7º north of the equator, having a warm and humid climate. The average temperature is consistently high (about 28ºC) during daytime throughout the year, with small daily thermal swings of about 5ºC to 10ºC. Relative humidity is high (about 84%), and the average daily wind speed is only about 1m/s (www.timeanddate.com, 2019). This often causes discomfort for the building inhabitants especially during daytime. We use vast amount of energy to cool our buildings which leads to high CO2 emissions that contribute to global warming and climate change. Traditional and indigenous architecture are often climate responsive, built using minimal resources and use less energy. "The traditional Malay house contains the wisdom of building and living sustainably with nature" (Yeang, 2014). We need to understand the principles behind the existing design features of traditional and vernacular architecture for potential solution to reduce cooling energy in modern buildings.

The Kutai house is the oldest known type of traditional Malay house found in the region of Perak, Malaysia dated back to the year 18th hundred. Ariffin and Talib (2005) urge more research on traditional Malay houses since they are quickly decaying due to poor maintenance and care. Nipah or sometimes sago palm leaves was originally used for the roof. Since its availability and demand is now scarce, and difficult to maintain, most of the remaining Kutai houses roof materials were replaced with zinc, steel or Onduline roof sheets. This could cause detrimental effect on the indoor thermal comfort condition (Sari et al., 2019). However, minimal quantitative research has been done to prove that the Kutai house is thermally comfortable. The aim of this paper, therefore, is to evaluate the Kutai house's indoor daytime thermal comfort condition using field study measurements of current indoor environmental conditions and bioclimatic analysis. Two case studies of Kutai houses: the Tok Seindera Bongsu's house (RTSB) built in 1840s and Iskandar Rasul's house (RKR) built in 1880s were employed.

LITERATURE REVIEW

Kutai House

Traditional Malay houses typically consist of the main house or space (rumah ibu), entrance space or balcony (serambi), guest area (anjung), and kitchen (rumah dapur). The main house and kitchen are separated by a space known as 'selang' which sometimes serve as entrance for women. The oldest and simplest type of Kutai house is known as Kutai Asli which consist of only the main house (rumah ibu) and has only one bedroom. Later, other types; Kutai Anjung and Kutai Anjung Beranda; were built which has guest area (anjung) and balcony (serambi) added. The size of the main house is determined by the number of columns they have which are either 12 or 16. Figure 1 shows the typical forms of Kutai houses. Kutai house has a distinct long roof ridge that is slightly curved in the middle and cantilevered gable ends. The roof has a high pitch of about 50º to 60º angle intended to allow the rain to easily drain down. The original roof was usually made of Nipah palm leaves. The main material for structures, floors and walls is hardwood timber (RTSB) (Figure 6) while tepas or bamboo weave are sometimes used for the walls (RKR) (Figure 7).

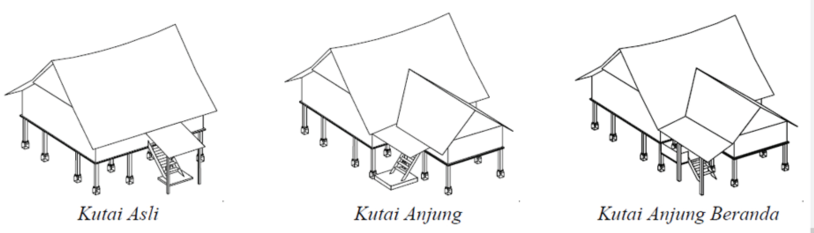

Figure 1: Typical form of Kutai House
(Source: Ariffin & Talib, 2005)

Bioclimatic Design

Bioclimatic design was coined first by Olgyay in 1953 (Evans, 2007). Typical bioclimatic design approach for houses in hot and humid climate recommends solar protection, cross ventilation, and lightweight construction. Lechner (2014) described the approach as passive design method which consists of solar control, structural control, and ventilation.

The purpose of solar control is to avoid heat gain from the solar radiation by suitable building orientation and using shading devices. Besides, structural control requires appropriate use of building materials to reduce heat transfer into the building, while ventilation removes the heat from the building and cools the building and its' inhabitants.

In the case of low-rise buildings, most of the heat (80%) enters through the roof (MS2689:2017). Heat gain through the walls and windows mainly occur during morning and evening when the sun's altitude is low. Heat is transferred into a building mainly by conduction through the building envelope (roof, and east and west walls) and by radiation through the unshaded window openings. Thus, knowing the material properties of the envelope: conductivity, k-value, resistance, R-value, surface colour, and thickness is therefore important since it can influence the heat conduction into the building. Overall heat transfer coefficient, U-value or U-coefficient indicates the amount of heat that flows across a building envelope (roof or wall). U-value is one on the factors that reduce the overall thermal transfer value (OTTV) score required for energy efficiency (Ismail & Zainonabidin, 2016). U-value is the reciprocal of the total thermal resistance, R, of a building envelope that may consists of several components of different materials. U-value is the inverse of RT, where RT is the total resistance of all components of a wall or roof including the resistance of air at its internal and external surface. RT = Rsi + R1 + R2+ Rn + Rso where Rsi and Rso is the internal surface air resistance and external surface air resistance respectively. Resistance of a material, R = d/k, where d is the thickness & k is conductivity of the material. Low U-value and high R-value is better in reducing the heat gain through the building envelope (Littlefield, 2018).

Albedo is the measure of a surface's reflectivity of solar radiation which has a value between 0 and 1 (Lechner, 2014). A white surface will have an albedo close to 1 because it reflects most of the solar radiation. On the contrary, black surface absorbs most the solar radiation, thus having an albedo near to 0. The temperature difference between the surface and ambient air temperature is only about 10ºC if high albedo roof is used compared to 50C for low-albedo roof (Akbari & Konopacki, 1998). This can lead to cooling energy savings in hot climates. Other researchers have shown that by changing the albedo of roof and walls from medium dark colour (0.3) to light colour (0.9) can reduce the total air conditioning energy by 20%. Grass has an albedo of 0.2 to 0.3, corrugated roof's albedo is 0.1 to 0.2, and highly reflective roof's albedo is 0.6-0.7 (Lechner, 2014).

In addition, ventilation of buildings helps to cool the building structure and interior space by exchanging warm indoor air with cooler outdoor air. Natural ventilation can be provided by using differential wind pressure, and air buoyancy through stack effect. Locating the windows or openings at suitable positions at windward and leeward side is important as to induce the indoor air movement.

Thermal Comfort

The air temperature, relative humidity, air movement and mean radiant temperature are the main environmental factors that influence thermal comfort (Lechner, 2014). Other factors that may affect thermal comfort are clothing and the human's metabolism. The surrounding air temperature is the main influential factors that determine thermal comfort. The human body exchanges heat with its surrounding environment by conduction, convection, radiation and evaporation (physiological cooling). The human body needs to lose heat to the surrounding environment in order to maintain its body temperature and be comfortable (Rosenlund, 2015). High environmental temperatures reduce the heat loss rate from the human body. On the other hand, high relative humidity means that the air contains lots of water vapour, while high relative humidity at high air temperature makes the human body sweat. The evaporation of sweat causes the human body to cool down. Besides, air movement helps to increase the rate of evaporation. For comfort, mean radiant temperature (MRT) needs to be close to the air temperature values. Additionally, higher MRT causes the exposed human skin to feel the radiant heat radiated by the surrounding surfaces.

Olgyay's bioclimatic chart (1963) (Figure 3) provides in graphic form the environmental parameters that defines the 'comfort zone'. 'Comfort zone' is "the range of climatic conditions within which the majority of persons would not feel thermally discomfort" (Givoni, 1998). In addition, the bioclimatic chart provides compensatory measures, for example, an increase of air velocity to offset high air temperature and relative humidity. Olgyay (1963) suggested the usage of bioclimatic chart as guidelines for lightweight buildings in hot humid countries where there was little temperature fluctuations between indoor and outdoor. Givoni (1970) then developed a variant of Olgyay's concept using psychrometric chart that a number of zones for different climates and design strategies can be added (Figure 4). Givoni's psychrometric chart (1970) defines the comfort zone for naturally ventilated (NV) buildings: relative humidity ranges from 28% to 100% when air temperature is at 20ºC, and from 24% to 55% at air temperature of 32.5ºC. Furthermore, reduced air temperature is required for comfort from 32.5ºC to 26ºC when relative humidity increases from 55% to 100%.

Nicol and Humphreys (2001) proposed the theory of 'adaptive comfort' whereby human makes adaptation by changing clothes and activity levels to achieve comfort. Figure 2 shows a version of the 'adaptive comfort model' where the indoor thermal comfort is dependent on the average external temperature (ASHRAE standard, 2004). Based on the adaptive thermal comfort model (Figure 2), the average temperature (about 28ºC) (www.timeanddate.com, 2019), thermal comfort (80% satisfied) for the building's interior in Malaysia should be between 21ºC to 31ºC.

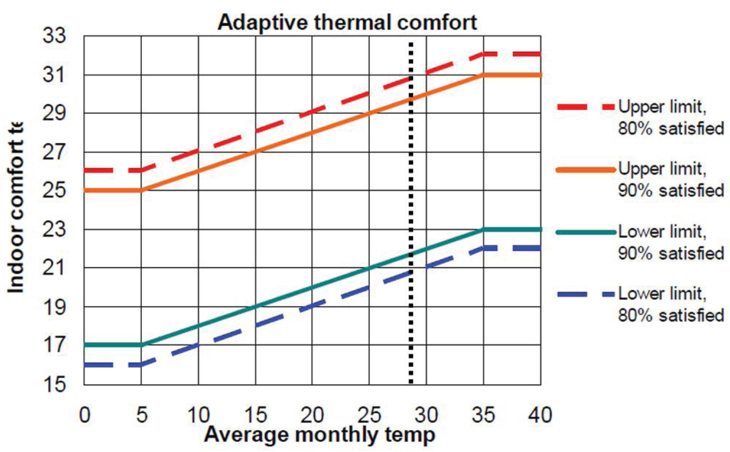

Figure 2: Adaptive Thermal Comfort Based on the Average Monthly Outdoor Temperature. Dotted Vertical Line Indicate Comfort Range for Malaysia
(Source: ASHRAE Standard 55:2004)

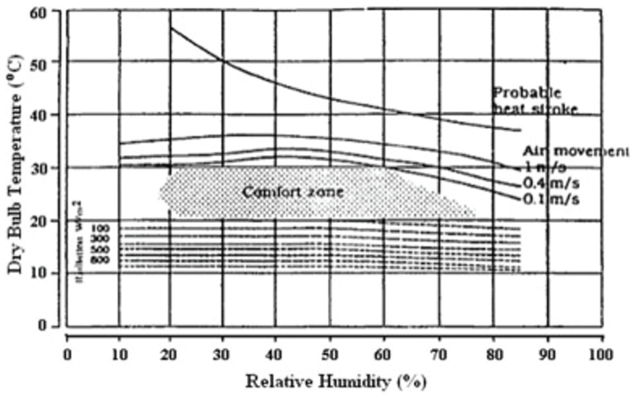

Figure 3: Olgyay's Bioclimatic Chart Showing the Comfort Zone
(Source: Olgyay, 1963)

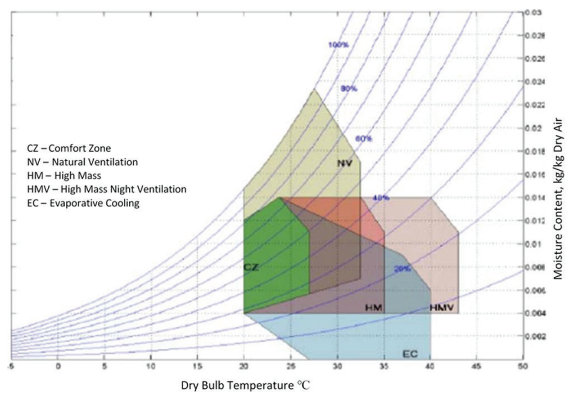

Figure 4: Givoni's Psychrometric Chart (1970) Showing Comfort Zone for Naturally Ventilated Building (NV)
(Source: Al-Azri et.al, 2012)

METHODOLOGY

Qualitative study on the bioclimatic design approach of the two original Kutai houses were studied (Figure 5). Overall heat transfer coefficient (U-value) of the existing building envelope were calculated to determine the roof and wall's thermal performance. The U-value calculation was described in the previous section. For calculation purposes, the material properties (r-value or k-value, and thickness) of each material that forms the roof and wall components must be looked into and can be found in various references or material's fact sheet. The resistance, R of air film is a constant (Littlefield, 2018). For comparison purposes, the researchers also calculated the U-values of nipah (originally used for Kutai house), onduline (alternative material sometimes used) roofs, and both zinc and onduline roofs with insulations included as roof component.

In addition, field measurement data of indoor air temperature, relative humidity and air speed were obtained to evaluate the environmental thermal comfort level in the Kutai houses on a clear day during daytime at one-hour interval from 7am to 7pm. The field measurements were taken on different days in December, 2016. Measurements were taken at various zones (Figure 5) using Multi-Parameter Ventilation (Velocity Plus). The hourly average results were plotted on a bioclimatic chart for analysis. The thermal comfort ranges proposed by Givoni (1970) was used as standards for naturally ventilated buildings. The research does not consider clothing and human's metabolism since they are not part of building design parameters.

RESULTS AND DISCUSSIONS

Bioclimatic Design Approach

Solar Control

The Kutai houses are oriented to face the river rather than align with the sun's daily path (east-west). The floor plans orientation with the location of windows are shown in Figure 5. Using the roof ridge axis as a reference, RTSB's orientation is actually SouthEast-NorthWest (SE-NW), having the NorthEast (NE) and SouthWest (SW) walls and windows shaded by the roof overhanging eaves (Figure 6). RTSB's SouthEast wall is exposed to the radiation during morning, while its NorthWest wall is exposed during the afternoon. RKR's orientation is NorthEast-SouthWest (NE-SW) with SouthEast and NorthWest walls and windows shaded by the roof overhang during morning and afternoon (Figure 7). Its NorthEast and SouthWest walls are exposed to the radiation during morning and afternoon respectively. All windows are made of timber that can be closed when needed to provide protection against the solar radiation in the morning and evening.

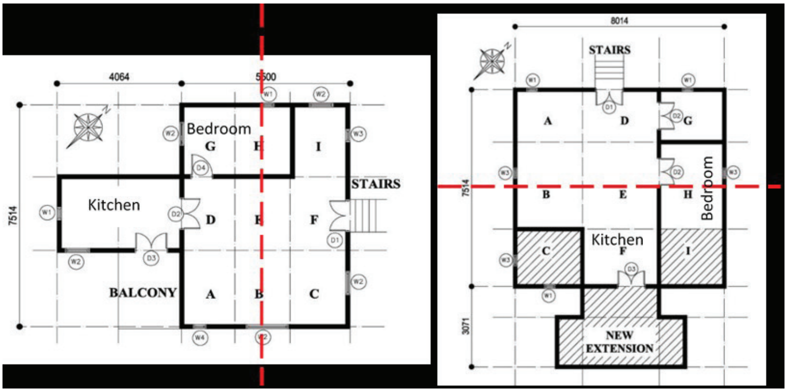

Figure 5: Floor Plan of Kutai Houses. Tok Seindera Bongsu's House (Left), Kanda Rasul's House (Right). Environmental Measurements were Taken in Various Zones Indicated by the Alphabet
Source: Author

Figure 6: Tok Seindera Bongsu's House (RTSB). View from east (Top left). Southeast Elevation (Top right). View from north (Bottom left). Northwest elevation (Bottom right)
Source: Author

Figure 7: Windows of Kandar Rasul house (RKR). View from west (Top left). View from north (Top right). Ventilation Holes (Bottom left).
(Source: Rashid, 2017 (Bottom left)

Structural Control

The overall heat transfer coefficient (U-value) of Kutai houses roof and wall components were determined (Table 1 to 7) and the comparison is shown in Figure 8. For comparison purposes, U-values of Nipah roof, and zinc roof and onduline roof with the addition of insulation and ceiling as part of the roof component were also calculated (Table 1 to 5). The U-value of Nipah roof is low (0.4W/m2K) compared to Zinc roof (5.56W/m2K) and onduline roof (4.64W/m2K). Nipah roof would have significantly reduced the heat transfer into the houses, thus reducing the indoor air temperature. To match the Nipah roof U-value, insulation of 10cm thick with conductivity of 0.039W/mK need to be added to the zinc and onduline roof component. Zinc roof has higher surface reflectivity (albedo of 0.6 to 0.7) than onduline roof and thus would reflect more heat and provide greater energy savings for cooling (Akbari et al, 1992). For the walls, bamboo weave's (RKR) U-value is significantly higher than timber (RTSB) since it is thinner and has higher conductivity.

Table 1: U-Value Calculation of Nipah Roof

Roof components	Thickness, d (m)	Conductivity, k (W/mK)	Resistance, R (m2K/W)	U-value (W/ m2K)
Nipah palm leaves*	0.07	0.03	2.33	-
External air film	-	-	0.04	-
Internal air film	-	-	0.13	-
TOTAL			2.50	0.40

(Source: *Al Nesearawi, 2008)

Table 2: U-Value Calculation of Zinc Roof

Roof components	Thickness, d (m)	Conductivity, k (W/mK)	Resistance, R (m2K/W)	U-value (W/ m2K)
Zinc	0.004	0.4	0.01	-
External air film	-	-	0.04	-
Internal air film	-	-	0.13	-
TOTAL			0.18	5.56

Source: Author

Table 3: U-Value Calculation of Onduline Roof

Roof components	Thickness, d (m)	Conductivity, k (W/mK)	Resistance, R (m2K/W)	U-value (W/ m2K)
Onduline*	0.003	0.066	0.045	-
External air film	-	-	0.04	-
Internal air film	-	-	0.13	-
TOTAL			0.215	4.64

(Source: *onduline.co.uk)

Table 4: U-Value Calculation of Zinc Roof with Insulation and Bamboo Weave Ceiling

Roof components	Thickness, d (m)	Conductivity, k (W/mK)	Resistance, R (m2K/W)	U-value (W/m2K)
Zinc	0.004	0.4	0.01	-
Insulation	-	-	-	-
(mineral wool *)	0.1	0.039	2.56	-
Ceiling (bamboo)	0.003	0.162	0.019	-
External air film	-	-	0.04	-
Internal air film	-	-	0.13	-
TOTAL			2.76	0.362

(Source: *Lechner, 2014)

Table 5: U-value Calculation of Onduline Roof with Insulation and Bamboo Weave Ceiling

Roof components	Thickness, d (m)	Conductivity, k (W/mK)	Resistance, R (m2K/W)	U-value (W/m2K)
Onduline	0.003	0.066	0.045	-
Insulation	-	-	-	-
(mineral wool)	0.1	0.039	2.56	-
Ceiling	-	-	-	-
(bamboo weave)**	0.003	0.162	0.019	-
External air film	-	-	0.04	-
Internal air film	-	-	0.13	-
TOTAL			2.80	0.357

(Source: *Lechner, 2014

Table 6: U-Value Calculation of Hard Wood Timber Wall (RTSB)

Wall components	Thickness, d (m)	Conductivity, k (W/mK)	Resistance, R (m2K/W)	U-value (W/m2K)
HW timber board	0.015	0.17	0.088	-
External air film	-	-	0.04	-
Internal air film	-	-	0.13	-
TOTAL			0.258	3.87

Source: Author

Table 7: U-Value Calculation of Bamboo Weave Wall (RKR)

Wall components	Thickness, d (m)	Conductivity, k (W/mK)	Resistance, R (m2K/W)	U-value (W/m2K)
Bamboo weave	0.003	0.55	0.005	-
External air film	-	-	0.04	-
Internal air film	-	-	0.13	-
TOTAL			0.175	5.70

Source: Author

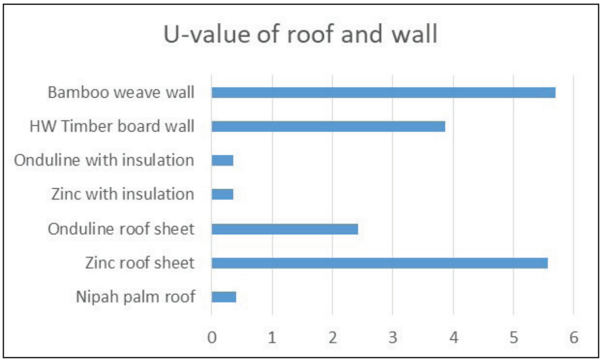

Figure 8: U-value Comparison of Different Roof and Wall Materials
Source: Author

Ventilation

Kutai house's layout is open-planned and normally has only one bedroom. Lattices at the top of the bedroom partitions are installed to allow free flow of air through the house. All the Kutai houses typically have the same number of windows and fixed window locations. The number of windows is significantly less and smaller than in other types of traditional Malay house. The location of the windows allows cross ventilation from many different wind directions. The windows can be open or closed depending on the occupants' needs. Normally, windows are opened during the day and closed at night. There are two segments of windows which is low and horizontal for people who are sitting on the floor, and vertical for people who are standing or walking. Apart from the windows, there are also many ventilation holes to enable the wind going into the house for ventilation and cooling, and also for removing hot stale air and humidity out (Figure 6 & 7) as the floor is built high on stilts, thus, higher velocity wind flow in the house is expected.

Field measurement results and bioclimatic analysis

Figure 9 shows the scatter results of air temperature against relative humidity plotted onto a bioclimatic chart. The 'comfort zone' parameters recommended by both Olgyay (1963) and Givoni (1970) are shown. Most data for both Kutai houses falls inside Givoni's 'comfort zone' for naturally ventilated buildings, proving that the houses are thermally comfortable even with zinc roof. The use of nipah roof, having lower U-value (0.4W/m2K) (Figure 8) than zinc (5.56W/m2K) and onduline roof (4.64W/m2K), would result in a lower indoor air temperature since less heat would be transferred into the houses. This would have pushed all the data down into the comfort zone required for naturally ventilated building as recommended by Givoni (1970). Zinc, despite having higher U-value than onduline roof, has higher albedo and would have more heat than onduline roof and produce slightly cooler indoor environment.

Figure 10 shows the graph of air temperature, TA against time in the Kutai houses studied. Upper limits of comfort set by Givoni (1970) and adaptive comfort (80% satisfied) is shown in the graph. The maximum temperatures in both houses were below the upper comfort limit suggested by Givoni (1970). RKR records temperature above the upper limits of adaptive thermal comfort (difference of 1ºC) for only about 1 hour at noon. The minimum air temperature, TA recorded at 7am was 23.2º in RKR, which is 1.6ºC lower than in RTSB (24.8ºC). However, the maximum TA recorded in RKR (32ºC) was higher than in RTSB (29.6ºC) at noon. Indoor temperature swing was 8.8ºC in RKR and only 4.8ºC in RTSB. Overall, temperatures in RKR were lower in the morning than in RTSB but higher from 11am onwards. Since the main difference between RKR and RTSB was the material used for their walls, it might be possible that the RKR's thin bamboo weave walls and higher conductivity than timber allowed the heat to transfer quickly across the walls thus producing greater indoor temperature swing. Hence, the resultant U-value of bamboo weave wall is higher than timber wall (Figure 8) causing the higher temperature swing in RKR.

Figure 11 shows that the relative humidity (RH) was higher when the air temperature was low. The maximum RH recorded was 95% in RTSB and 95.37% in RKR. The minimum RH recorded was 73.33% in RTSB and 65.26% in RKR. The average RH in RTSB and RKR was 87.15% and 81.97% respectively. Relative Humidity could be lowered if the air speed inside the houses was higher. Besides, the bioclimatic chart (Figure 10) also shows that the air speed of 0.4m/s to 1m/s could reduce the indoor relative humidity and air temperature.

Figure 12 shows graph of air velocity, V recorded in the Kutai houses studied. Although high wind velocity was expected inside the Kutai houses due to the numbers of windows and ventilation holes found, the maximum air velocity recorded was only 0.18m/s in RTSB. The average air velocity measurement was higher in RTSB (0.07m/s) than in RKR (0.04m/s). The speed of less than 0.25m/s is considered unnoticeable except at low air temperatures (MS2680: 2017). However, wind flow is expectedly unpredictable as breeze may not be available, and this may also be influenced by other constraints that could prevent cross ventilation. Further air speed measurements inside and outside the Kutai houses are therefore needed to confirm the findings.

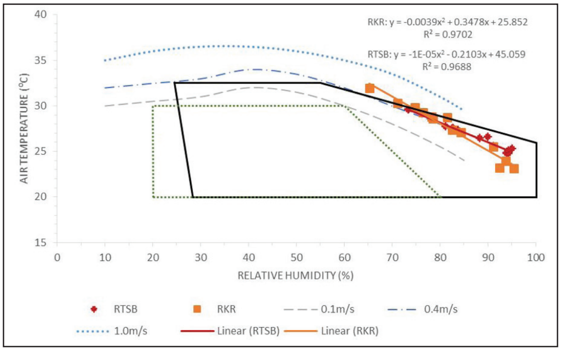

Figure 9: Results of Air Temperature Against Relative Humidity
Source: Givoni (1970)

The solid line box represents the comfort zone based on Givoni (1970). Dotted box represents Olgyay's (1963) comfort zone. Wind speed requirements (dotted & dashed lines) are also plotted based on Olgyay's bioclimatic chart.

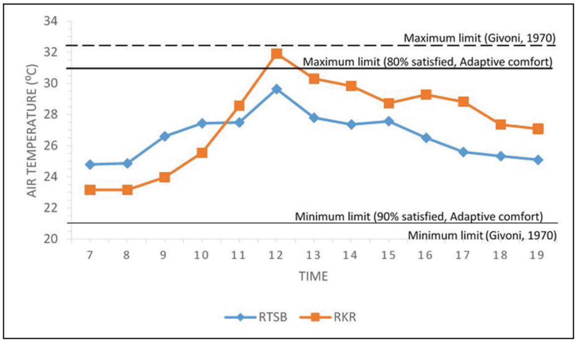

Figure 10: Charts Showing the Results of Air Temperature, TA Against Time.
Source: Givoni (1970).

The dotted line indicates the maximum limit for comfort recommended by Givoni (1970). The solid line indicates the maximum limit for Adaptive Comfort (80% satisfied).

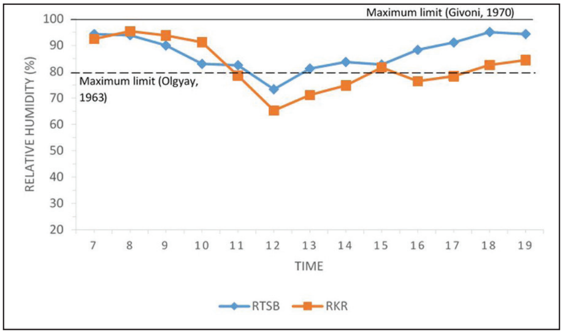

Figure 11. Charts showing the Results of Relative Humidity, RH Against Time
Source: Author

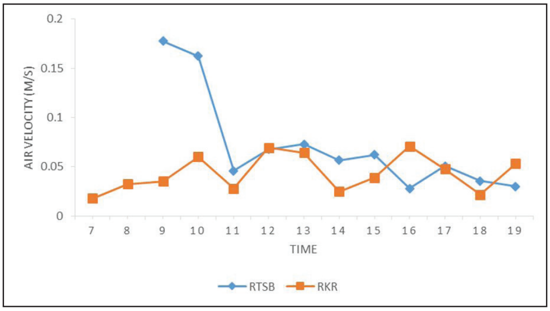

Figure 12: Charts showing the Results of Air Velocity, Vs Against Time
Source: Author

CONCLUSION

The bioclimatic analysis shows that the Kutai houses studied are thermally comfortable during daytime despite the use of zinc roof. Kutai house using timber wall (RTSB) is more comfortable than Kutai house using bamboo weave wall (RKR). Most of the data are within the comfort zone for naturally ventilated buildings. The maximum TA recorded in both Kutai houses are below Givoni's upper limit for air temperature. Olgyay's bioclimatic chart indicates that air speed of 0.4m/s is required to offset the effect of high air temperature and relative humidity. The air velocity results are unexpectedly low despite the number of windows and ventilation holes provided. It is recommended that future measurements will include outdoor and indoor wind speed data for comparison. The main factors affecting the indoor thermal comfort conditions is the overall heat transfer coefficient of the building enclosures. The low U-value of nipah palm roof originally used in Kutai houses suggests that nipah palm would have lowered the indoor air temperatures and provide better thermal comfort condition. Nipah palm U-value (0.4W/m2K) should be set as benchmark for roof's U-value in Malaysia. Metal (zinc) and onduline roof have higher U-values than nipah. Adding insulation of at least 0.039W/mK and 0.1m thick to the roof components will lower the zinc and onduline roof's U-value close to U-value of nipah roof. U-value of wall of RKR was found to be higher than RTSB due to the thinness of bamboo weave wall and its higher conductivity than timber, which resulted in higher air temperature swing recorded in RKR.

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REFERENCES

Abd. Rashid, M.S. (2017). *Rumah Kutai, Documentation of Memories*. Institut Darul Ridzuan, Malaysia.

Akbari, H., et al. (1992). Cooling Our Communities: A Guidebook on Tree Planting and Light-Colored Surfacing. EPA and DOE/Lawrence Berkeley Laboratory.

Akbari, H., Konopacki, S. (1998). The Impact of Reflectivity and Emissivity of Roofs on Building Cooling and Heating Energy Use. Proceedings of Thermal VII: Thermal Performance of the Exterior Envelopes of Buildings VIIs, p.29-39. American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc.

Al-Azri, N., Zurigat, Y. & Al-Rawahi, N. (2012). Development of Bioclimatic Chart for Passive Building Design in Muscat, Oman. International Conference on Renewable Energies and Power Quality (ICREPQ '12), Santiago de Compostela, Spain. Vol. 1, No.10.

Al-Nesearawi, M. (2008). Palm Leaf as a Thermal Insulation Material. IBN AL-HEITHAM J. for *Pure & Applied Science*, 21 (2).

Ariffin, M., & Talib, A. (2005). Perak Malay (Kutai) Architecture: A Methodological Approach in Extensive Survey and Analysis. http://www.fp.utm.my/epusatsumber/listseminar/7.QRAM05/Session1/11.Ariffin.pdf

Effendy, T. (2014). Rumah, An Ode to the Malay house. Areca Books and Ken Yeang.

Evans, J. M. (2007). *The Comfort Triangles: A New Tool for Bioclimatic Design*, PhD.

Givoni, B. (1998). *Climate Considerations in Building and Urban Design*. John Wiley & Sons Inc.

Hashim, W., & Nasir, A. H. (2011). *The Traditional Malay House*. Institut Terjemahan Negara Malaysia.

Lechner, N. (2014). *Heating, Cooling, Lighting, Design Methods for Architects* (4th ed.). John Wiley & Sons Inc.

Littlefield, D. (Ed.). (2018). *Metric Handbook, Planning and Design Data* (6th ed.). Architectural Press.

Malaysian Standard MS2680:2017, *Code of Practice on Energy Efficiency and Use of Renewable Energy for Residential Buildings.* (2017). Department of Standards Malaysia.

Olgyay, V. (1963). *Design with Climate, Bioclimatic Approach and Architectural Regionalism.* Princeton University Press.

Onduline.co.uk (2018). https://onduline.co.uk/products/onduline/.

Rosenlund, H. (2000). *Climatic Design of Buildings using Passive Techniques*. Building Issues, 10 (Number 1). https://www.research gate.net/publication/238104641.

www.timeanddate.com, (2019). https://www.timeanddate.com/weather / malaysia/ipoh/climate.