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Comfort level of a cross laminated timber (CLT) structure from Sesenduk timber in Forest Research Institute Malaysia

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Thermal comfort is a key criterion to be considered to ensure a healthy indoor environment for the occupants. In Malaysia, cross laminated timber (CLT) is gaining favour in the building sector owing to the depletion resources of timbers. An 18 m^2 cross laminated timber (CLT) structure were built at the Forest Research Institute Malaysia. However, there is lacking of information on the thermal comfort of CLT structure in Malaysia. Therefore, this study aimed to determine the temperature and relative humidity variation within the CLT structure over a period of one year. The environmental parameters such as temperature and relative humidity were recorded daily at every 30 minutes from 730 to 1730. The data recording was implemented for over a year from January 2018 to December 2018. Graphs were plotted using mean monthly data as well as the hourly data on the specific day. The results revealed that the CLT structure provide a sound insulation against heat as when the temperature outside is scorching hot, the occupants can still find comfort in the house. Nevertheless, there is still some rooms of improvement for the CLT structure to be implemented in the future study, especially the ventilation rate.

Keywords: Thermal Environment, Cross Laminated Timber, Building Structure, Temperature, Relative Humidity

1. INTRODUCTION

Man has been constructing buildings using basic available material such as clay, stone and timber. But due to technology development, changes in environment and human perception, this material is now being replaced with durable, low maintenance and easily available material such as concrete, bricks and engineered timber. Selection of building material is important to achieve optimum energy efficiency and thermal comfort in a building such as timber usage that would adapts to the local climates and conditions of a country (Samuel et al., 2017). Owing to their renewable in nature and low impact to environment, timbers are again being favored by the construction and building sector. Cross laminated timber (CLT) is one of the engineered timber products that demonstrate promising prospect in the building sector. CLT is typically fabricated from at least 3 lamellae of lumbers in rectangular shape and bonded perpendicularly using structural adhesive as binding agent (Yusof et al., 2019). Due to their high strength and stiffness, application of CLT for primary structural material in multi-storey construction

often resulted in satisfactory outcome (Lineham et al., 2016). According to Mallo and Espinoza (2014), CLT is deemed as a revolutionary engineered timber product that are able to bring enormous changes to the construction and building industry. Substitution of concrete with CLT in a seven-storey building could reduce more than 30% of energy consumption as well as 40% emission of carbon dioxide (Liu et al., 2016). In addition, more than half of the CLT buildings could be recycled upon the completion of the project (Liu et al., 2016).

When staying in a building, the comfort level of the occupant is the most important factor in determining the performance of the building itself. Yahya et al. (2014) has identified four main factors that influence the occupant's comfort level in a building, namely thermal, acoustic, visual comfort and personal control of the building's environmental condition. Particularly for the countries in hot tropic such as Malaysia, thermal comfort exerts the most influence to one's comfort levels (Jamaludin et al., 2014). According to the International Standard ISO, thermal comfort is best defined as condition of mind which expresses satisfaction with the thermal environment. It is the condition where a person is comfortable or to feel either too hot or too cool it which could lead to discomfort (Adekunle and Nikolopoulou, 2016).

Al-Tamimi and Syed Hadzil (2011) reported that the annual mean temperature in Malaysia is 26.4 °C with average daily maximum temperature is 34.5 °C and average daily minimum at 23 °C. While the annual relative humidity ranges within 74 % and 86 %. In Malaysia, the season change between hot and monsoon season. They further reported that in November to March the temperature would drop to 26 °C due to the monsoon season. After that, the season remains hot and the temperature may sometime may rise to 32 °C or higher. Indoor environment is influenced by the outdoor condition, the factors affecting indoor thermal environment are crucial in improving a comfortable and healthy environment in residential building.

Studies regarding the thermal comfort of a CLT buildings are rather limited. Adekunle and Nikolopoulou (2016) compared two buildings built with CLT and Structural Insulated Panel (SIP), respectively, in terms of thermal comfort and temperatures during summertime in London, UK. The thermal comfort surveys of the study revealed that about 8 out of 10 occupants in the CLT buildings feel warm. On the contrary, only about 4 out of 10 occupants of the SIP building gave the same answer. Although the indoor temperature of both of the buildings were considered within the comfort range, the overheating risks for both of the CLT and SIP building were frequenter compared to the building built with conventional building materials, for example bricks. Another study by Adekunle (2019) has determined the comfort level and stress indices of the occupants in a CLT school building located in the Northeast US in different seasons. Based on the results obtained, there was no thermal stress reported among the respondents. However, the chances of moderate thermal stress exist during the warmest month of the year. Therefore, design strategies that could lessen the discomfort and stress in buildings is necessary. In Malaysia, where the development of CLT is still in its initial phase, the relevant data is basically non-existing.

With depleting resources for timber, the use of cross laminated timber (CLT) for residential and public structures has been widely used in Europe and America. However, in the recent years, it is already reaching the Asian shores including Malaysia. While the public are aware of the post and beam timber construction, CLT as building material is relatively new. Addressing the present issues relating to sustainability in the built environment and thermal comfort to the already warm environment, the introduction of cross-laminated timbers in Malaysia is seen as timely. Dissimilar to the developed Asian countries such as Japan and China, CLT development in Malaysia has just started. There are still many gaps to be filled by future researches using domestic wood species. Fortunately, development of CLT has received vigorous support from Malaysian government as a grant was awarded under the E-science fund to the Forest Research Institute Malaysia (FRIM) by the Ministry of Science, Technology and Innovation (MOSTI) and another grant under the Eleventh Malaysia Plan (2016-2020) or RMK-11.

As a pioneer in the field, FRIM has constructed an 18 square meter CLT structure in 2016 using local species, sesenduk (*Endospermum* spp.) wood (Hamdan et al., 2017). The rectangle cabin structure gave an insight experience on the preparation, manufacturing, properties, constructing as well as studying the in-service performance of the CLT structure. There are many studies conducted on the thermal

comfort in different types of buildings including timber houses in Malaysia (Nazhatulzalkis et al., 2015; Cheong et al., 2020; Nasir and Hassan, 2020), however, no similar information is available on the thermal comfort in a CLT structure. This study was initiated to determine the temperature and relative humidity variation within the CLT structure over a period of one year. This would then be use to gauge and as reference for similar construction in the future.

2. MATERIAL AND METHOD: DESCRIPTION ABOUT CLT STRUCTURE

This study was conducted in a 3 m by 6 m by 75 mm thick CLT cubicle structure built in 2016 and located at FRIM, Kepong, Selangor (3.233924, 101.632551). The west side of the CLT structure is usually block from the sun by an adjacent building while the eastern side is exposed to both morning and evening sun (Figure 1). The CLT panel for the construction is made of sesenduk (*Endospermum spp.*) timber with a density of about 550 kg/m^3. The structure has doors at both ends but no windows. It does not have any ceiling and there are openings or gaps between the rafters and soffits (Figure 2). It is built on a concrete slab about 1 m from ground level with timber floor finish and uses cement tiles as roofing.

The structure functions as a showroom and not occupied most of the time. The doors are open when there are visitors and during monthly downloading of the data. There are no specific data collected on experience working in this CLT structure. Personal experience by the authors shared here is to give some indication. When there is occupant and visitors, both the doors are usually open. In the morning, between 9.00 am and 11.00am is slightly conducive but is quite humid. However, in the afternoon, between 2.30 pm to 3.30 pm as it gets warmer, it would normally quite bearable due to wind drafts present that crosses into the CLT structure.

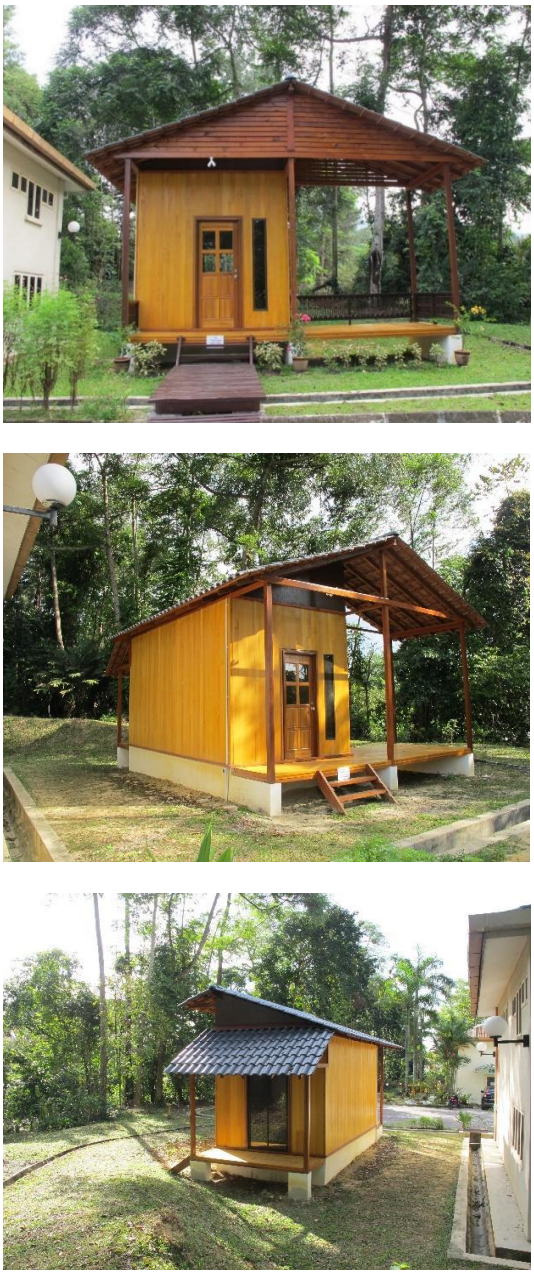


Figure 1. Front and rear elevation of the CLT structure

Figure 2. Interior of the CLT structure

METHODOLOGY

The environmental parameters measured are the temperature and relative humidity recorded at every 30 minutes using a 1 Watch Dog 1000 Series Micro Stations as shown in Figure 3 which recorded the internal room condition. The sensor was mounted on the internal wall about 1 m high to measure temperature and relative humidity that was recorded every 30 min. While a Wetness Sensor were placed on the external wall (Figure 4). The data were collected monthly from January to December 2018. The macro temperature for Kepong, Selangor recorded in 2018 was obtained from the regional weather station available online as comparison. The comfort band (environmental temperature range for comfort system) were adopted as stated in MS1525:2007 together with ASHRAE as comparison. The data were analyzed using the Excel spread sheet in which the mean values were derived from the monthly data.

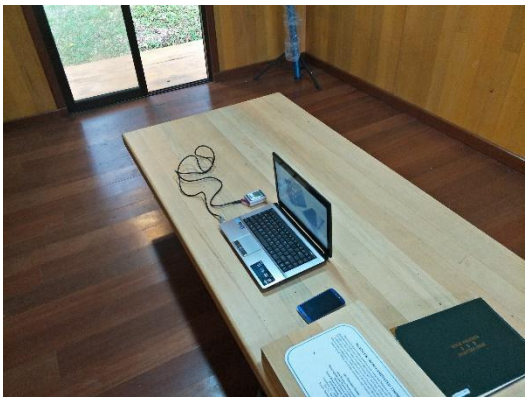
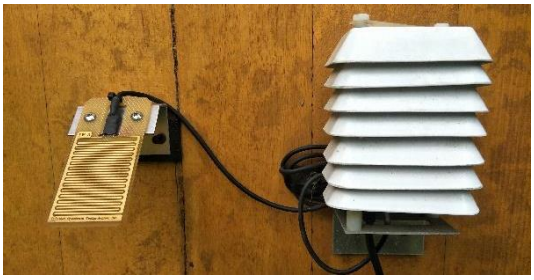


Figure 3. Micro Stations placed on the internal wall of the CLT structure



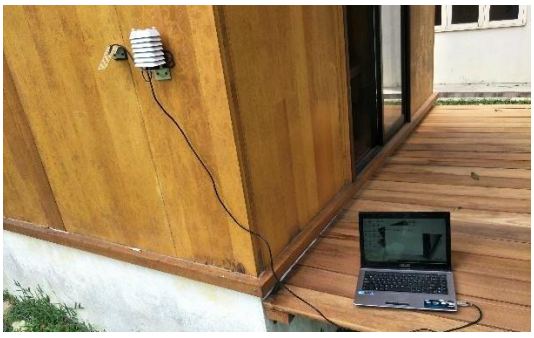


Figure 4. Wetness Sensor placed on the external wall of the CLT structure

3. RESULT AND DISCUSSION

Figure 5 shows the mean temperatures collected from the outside and inside of the CLT structure in January to December 2018 and were compared against the temperature recorded in Kepong, Selangor at the same period. As shown in the figure, one can see that the mean temperature outside and inside the CLT structure were 27.1 ˚C and 28 ˚C, respectively while for Kepong, Selangor was 27.8 ˚C. The lowest temperature was recorded in May 2018 where the temperature reading was 25.06 ˚C.

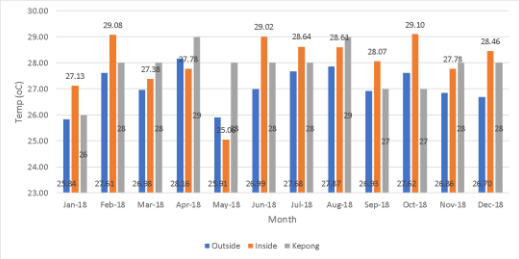


Figure 5. Mean monthly temperature outside and inside CLT structure compared to Kepong, Selangor

Figure 6 shows the mean monthly relative humidity (RH) recorded outside the CLT structure was 88.42 %. The lowest RH at 81.44 % was recorded in April while the highest was recorded in November 2018, which is 93.45 %. The mean RH inside the CLT structure is 81.42 % with the lowest at 75.29 % in February. On the other hand, in the month of November, the highest outside RH of 94.35 % were recorded while the inside was 84.28 %. Generally, the mean RH is higher than the recommended relative humidity for indoor comfort condition, which is not exceeding 70 % as mentioned by Djamila et al. (2014).

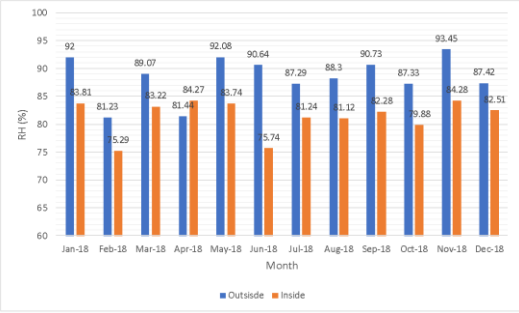


Figure 6. Mean monthly RH inside and outside of CLT structure.

Table 1 and 2 shows the date and time of the day in 2018 when temperature was higher than 38ºC outside and inside the CLT structure.

Table 1. Highest temperature outside and corresponding temperature inside by date and time

Date	Time	Temp Outside	RH	Temp Inside	RH
27 Feb	1200	39.4	52.0	29.9	72.6
6 Mac	1200	38.0	58.3	30.3	80.7
27 Apr	1200	39.4	52.0	27.6	87.4
19 July	1130	38.4	56.8	27.4	85.2
19 Oct	1130	38.4	56.8	30	77.1

The highest temperature outside of 39.4 ˚C was recorded in April 27, 2018 at 12 noon while the temperature at the same time inside the CLT house was 27.6ºC. The RH outside at this time was 52 % but the inside of the CLT structure remained a higher RH of 87.4%. In general, all the highest temperature over 38ºC at that particular month was recorded around 1200 noon. In Table 2, the temperature inside the CLT structure was exceeding 38 ˚C. The highest temperature was recorded on October 21, 2018 at 39.4 ˚C but it was already late in the evening between 1630 to 1700 hr when the temperature outside is 34.7 ˚C. The RH was 73.4% which is slightly higher than the recommended indoor comfort condition while RH outside was 55.1 %.

Table 2. Highest temperature inside and corresponding temperature outside by date and time

Date	Time	Temp Inside	RH	Temp Outside	RH
31 Jan	1600	38.5	75.9	34.9	62.2
11 Feb	1730	39.2	67.2	34.4	55.5
31 Mac	1600	38.5	75.9	29.5	82.1
31 May	1630	38.7	75.2	33.8	70.5
11 June	1730	39.2	68.7	25.9	94
17 July	1700	38.2	75.4	33.9	63.8
21 Oct	1630	39.4	73.4	34.7	55.1

The highest temperature outside the CLT structure was recorded in 27 April 2018 while the highest temperature inside was recorded in 21 October 2018. Therefore, the temperature data collected in these two days were detailed out in hourly basis from 730 hr to 1730 hr. Figure 7 below shows the hourly temperature outside in correspond to the inside of CLT structure recorded from 730 hr to 1730 hr taken on 27 April 2018. The temperature at 730 hr outside starts at 22.7 ˚C before peaking at 39.4 ˚C at 1200 hr and decreases to 34.2 ºC at 1730 hr.

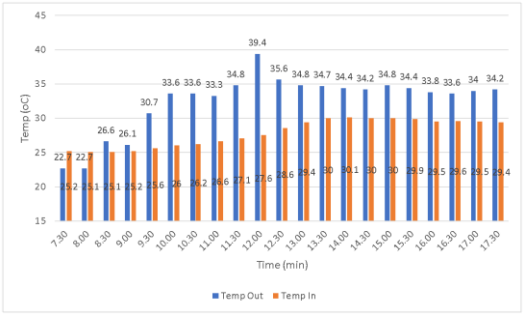


Figure 7. Hourly temperature recorded on 27 April 2018

Figure 8 shows that the temperature at 730 hr starts at 27.4 ˚C before it peaks at 39.4 ˚C and decreases to 38.4 ˚C at 1530 hr. This is quite in contrast to a study by Nazhatulzalkis et al. (2015) which recorded the highest indoor temperature at the master bedroom of a residential building in Kuala Lumpur was 32.6 ˚C at 1400 hr when the outdoor temperature in Kuala Lumpur was 36 ˚C. In comparison, the temperature for CLT structure recorded on October 21 at 1400 hr was 26.4 ˚C with RH of 84.6 %.

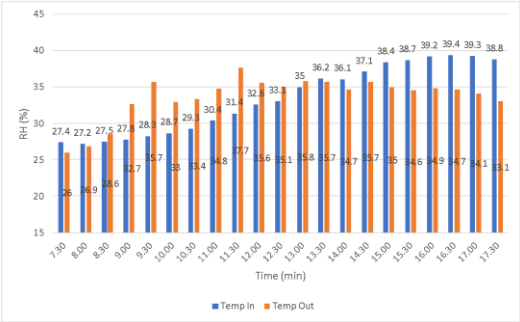


Figure 8. Hourly temperature recorded on 21 October 2018

In general, the temperature in Kepong is higher than outside the CLT structure. This may be due to the fact that the location of the CLT structure, which is within FRIM campus, is surrounded by lushly green vegetations. However, the mean temperature reading recorded in the CLT structure were mostly higher than outside temperature. This may be due to lack of cross ventilation and it being close most of the time which contributed to the higher temperature. Looking closer the temperature trend gave a good indication that the CLT structure have a sound insulation against heat. This is because when the temperature outside is scorching hot, the occupants can still find comfort in the house. And when the inside temperature rises which is probably due to stored heat in the CLT structure, it was already late in the evening.

A study conducted on a CLT school in the US shows that the average internal temperature in the main hall (a double-volume space on the ground floor – level 1) was 21.2 ˚C while the mean temperature of 24.1 ˚C was recorded in the classroom on the upper floor during the field investigation (Adekunle, 2018). Similar conducive internal condition could be created in future Malaysia CLT structure given that proper natural ventilation supplemented by mechanised cooling is taken into consideration during the design stage. On the other hand, Feriadi and Wong (2004) found that 26.03 ˚C was the preferred indoor operative temperature for naturally ventilated houses in Indonesia which

was 3.1 ˚C lower than the indoor neutral operative temperature. Tamaraukuro and Japo (2016) reported that at an average temperature of 29–32 ˚C and relative humidity of 78 %, human begin to experience a considerable level of thermal discomfort and also perceived that stress behaviours due to thermal discomfort may also affect their learning.

When RH is in the range of over 80 %, this would indicate that moisture molecules in the air are high. In such condition, human body cannot dissipate their body heat to the atmosphere and as a result would sweat a lot which make us feel hotter and uncomfortable. However, a study by Hwang et al. (2006) concluded that air temperature, air movement and mean radiant temperature have significant influence, but humidity has no statistical significance. This may be due that the occupants living in the tropics can accept the thermal range beyond the ASHRAE comfort zone. In this study, it seems that the occupants in the tropic environment such as Malaysia have a higher heat tolerance and can adapt to the environment that they are used to (Jamaludin et al., 2014).

Thermal comfort may vary between individual within the same environmental space. Study estimates that reasonable comfort can be established when a minimum of 80 % indoor occupants are feeling comfortable with the thermal environment (Radu, 2019). Hussein and Rahman (2009) also reported more than 80 % of the respondent is acceptable to their indoor thermal conditions even though it exceeded the ASHRAE standard indicating their tolerance and adaptation to the surroundings. This is supported by other studies on the comfort temperature in the tropical region is higher than other climate regions having concluded that the comfort temperature is higher in tropical regions, because of humans' ability on acclimatization (Li et al., 2010). Further in-depth study could be conducted to ensure more conclusive data be derived in order to compliment future CLT structure in Malaysia.

In general, the thermal comfort in this CLT structure can be improved by several options:

i. Placing cladding to the external wall that would function as cavity to vent warm air to infiltrate through the CLT panel into the space inside.
ii. Providing more opening to enable natural ventilation such as windows, louvres and voids.
iii. Introducing mechanical equipment such as exhaust fan, ceiling fan or air conditioning.

4. CONCLUSION

Cross Laminated Timber is a fast-growing building technology that is revolutionizing the construction industry and offering a more sustainable alternative to the typical building systems. Thermal comfort is important for health and well-being as well as productivity. The results from the study shows by complimenting design, technology and engineered timber such as CLT as an excellent insulating material, CLT would be able to provide a more conducive indoor condition. Timber having low thermal mass may affect or influence occupants' comfort in timber structure. Either by adding the number of CLT layers or in combination with other cladding material or introducing minimum mechanical intervention inside the CLT structure, it would undeniably help improve the internal thermal comfort. Since temperature in Malaysia is generally hot all year round, providing a conducive and cooler environment seems to be an obvious choice for the comfort of the inhabitants.

5. ACKNOWLEDGEMENT

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6. REFERENCES

Adekunle, T.O. 2018. Thermal comfort and heat stress in cross-laminated timber (CLT) school buildings during occupied and unoccupied periods in summer. Paper presented at the 10th Windsor Conference: Rethinking comfort, April 12-15, Cumberland Lodge, Windsor, UK.

Adekunle, T.O. 2019. Occupants' comfort and stress indices in a structural timber school building in the Northeast US in different seasons, Building Research & Information, 2019:1-18.

Adekunle T.O., Nikolopoulou M. 2016. Thermal comfort, summertime temperatures and overheating in prefabricated timber housing, Building and Environment, 103:21-35.

Al-Tamimi, N.A.M., Syed Fadzil, S.F. 2011. Thermal performance analysis for ventilated and unventilated glazed rooms in Malaysia (comparing simulated and field data), Indoor and Built Environment, 20(5):534-542.

Cheong, K.H., Teo, Y.H., Koh, J.M., Acharya, U.R., Yu, S.C.M. 2020. A simulation-aided approach in improving thermal-visual comfort and power efficiency in buildings, Journal of Building Engineering, 27:100936.

Djamila, H., Chu, C.M., Kumaresan, S. 20.), Effect of humidity on thermal comfort in the humid tropics, Journal of Building Construction and Planning Research, 2(2):109-117.

Feriadi, H., Wong, N.H. 2004. Thermal comfort for naturally ventilated houses in Indonesia, Energy and Buildings, 36:614-626.

Hamdan, H., Anwar, U.M.K., Mohd Izani, I., Iskandar, M., Mohd Tarmizi, M., Gan, K.S., Othman, M.D., Nooraznizam, A. & Muhammad Haziq, M.J. 2017. Cross Laminated Timber (CLT) structure: the first in Malaysia, Timber Technology Bulletin, No. 70.

Hussein, I. & Rahman, M.H.A. 2009. Field study on thermal comfort in Malaysia. European Journal of Scientific Research, 37(1):134-152.

Hwang, R.L., Lin, T.P. & Kuo, N.J. 2006. Field experiments on thermal comfort in campus classrooms in Taiwan, Energy and Buildings, 38(1):53-62.

Jamaludin, N., Khamidi, M.F., Wahab, S.N.A., Klufallah, M.M. 2014. Indoor thermal environment in tropical climate residential building, E3S Web of Conferences, 3:01026.

Li, B., Li, W., Liu, H., Yao, R., Tan, M., Ing, S., Ma, X. 2010. Physiological expression of human thermal comfort to indoor operative temperature in the non-HVAC environment, Indoor and Built Environment, 19(2):221-229.

Lineham, S.A., Thomson, D., Bartlett, A.I., Bisby, L.A., Hadden, R.M. 2016. Structural response of fire-exposed cross-laminated timber beams under sustained loads, Fire Safety Journal, 85:23-34.

Liu, Y., Guo, H., Sun, C., Chang, W.S. 2016. Assessing Cross Laminated Timber (CLT) as an alternative material for mid-rise residential buildings in cold regions in China—A life-cycle assessment approach, Sustainability, 8(10):1047. Mallo, M.F.L., Espinoza, O.A. 2014. Outlook for cross-laminated timber in the United States, BioResources, 9:7427-7443.

Nasir, M.H.A., Hassan, A.S. 2020. Thermal performance of double brick wall construction on the building envelope of high-rise hotel in Malaysia, Journal of Building Engineering, 2020:101389.

Nazhatulzalkis, J., Nurul Izma, M., Mohd Faris, K., Suriani Ngah, A.W. 2015. Thermal comfort of residential building in Malaysia at different micro-climates, Procedia - Social and Behavioral Sciences, 170:613-623.

Radu C. 2019. Thermal comfort in buildings: how to better control and predict, Available from: https://www.simscale.com/blog/2016/08/thermal-comfort-in-buildings/ [Accessed 26th March 2019].

Samuel, D.G.L., Dharmasastha, K., Shiva Nagendra, S.M., Prakash Maiya, M. 2017. Thermal comfort in traditional buildings composed of local and modern construction, International Journal of Sustainable Built Environment, 6(2):463-475.

Tamaraukuro, T.A., Japo, O.A. 2016. Perceived thermal discomfort and stress behaviours affecting students' learning in lecture theatres in the humid tropics, Buildings, 6(2):18.

Yahya, S.S., Ariffin, A.M., Ismail, M.A. 2014. Factors contributing to occupants' comfort: a survey among occupants of academic buildings in a public university. Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management, 7-9 January, Bali, Indonesia.

Yusof, N.M., Tahir, P.M., Lee, S.H., Khan, M.A., James, R.M.S. 2019. Mechanical and Physical properties of Cross-Laminated Timber made from *Acacia mangium* wood as function of adhesive types, Journal of Wood Science, 65(1):20.