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Assessment of thermal comfort in the mosque in Sarawak, Malaysia

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Abstract
In hot-humid climate, the mosque should be provided with an acceptable level of thermal comfort in order to seek serenity and focus for worship. The purpose of this study is to investigate the thermal comfort conditions in the Masjid Al-Muttaqin located in Kota Samarahan, Sarawak. The data were analysed using Corrected Effective Temperature (CET) index. The analysis shows that although the air velocity in the mosque is acceptable, due to the influence of high air temperature, thermal comfort is not achieved. A retrofit design by adding new materials and installing insulations on the existing roof are proposed and the results show significant improvement of thermal comfort inside the mosque.

Keywords: Thermal comfort; Hot-humid climate; Mosque; Corrected Effective Temperature (CET); Retrofit design.

1. Introduction
Mosque is a place of great importance for muslim for worship, therefore feeling comfortable and calm is crucial in order to seek a feeling of peace and serenity. Thus, thermal comfort and energy requirements should be investigated thoroughly in order to fulfill the requirements. However, only a limited number of studies have been conducted especially in Saudi Arabia to deal with these requirements of mosques and focusing on extreme climates [1, 2].
Thermal comfort considerations are vital in most buildings involving people occupancy. In hot-humid climate, the main concern is to get rid of heat from the space and those affecting body heat gains and losses. Air temperature, air velocity, air humidity, mean radiant temperature (MRT) as well as human clothing and activity levels are factors that determine the heat balance of a human body in a given thermal environment.
Most of researchers, reported that the range of air temperatures within which thermal conditions may be considered comfortable are between 16^{o}C to 29^{o}C [3, 4]. According to ASHRAE Standards [5] a recommended comfort temperature for people living under climatic condition such as those found in Malaysia is approximately 24^{o}C±1^{o}C. The actual requirement for a comfort temperature for people living in the South East Asian region was found to be higher [6]. The effect of air movement is critical as it helps to increase the efficiency of sweat evaporation and thus avoid discomfort due to moisture on the skin. In hot humid climate the most suitable air velocity for day comfort is in the range of 0.10 to 0.40 m/s and, indoor air velocities of 1.0 m/s are very pleasant and are acceptable up to 1.5 m/s, above that they are unacceptable [7]. Humidity affects comfort in a number of ways both directly and indirectly. As

suggested by most of researchers, the acceptable range of relative humidity should be around 35% to 70% [3-8]. Mean radiant temperature (MRT) affects the rate of radiant heat loss from the body. In hot-humid climate, the effects of radiation from the internal building surfaces are often neglected but should be considered as a main cause of discomfort in living spaces. Evan [3] reported that the MRT and air temperature are supposed to be in close agreement. In a hot-humid climate under intense solar radiation and with a poorly insulated building fabric, heat is rapidly conducted to the internal surface and is radiated into the living area causing discomfort.

Although mosques are important with a unique function and operation however the assessment of thermal performance, problems and possible remedies did not received adequate attention by researchers. This paper presents a study of the level of thermal comfort in the mosque located in Kota Samarahan, Sarawak, Malaysia which is to be expressed in Corrected Effective Temperature Index. Hanafi [9] and Ibrahim [10] used this index in their research on environmental design in hot humid countries and showed that the index is relevant to measured thermal comfort. ASHRAE [11] also mentions that the Corrected Effective Temperature(CET) is regarded as a good index for investigations in a warm and humid environment. Because of the success claimed by researchers using this index it has been adopted for use in this work for the assessment of indoor thermal comfort conditions in Malaysia under natural ventilation.

The comfort zone is based on four environmental parameters: (a) air temperatures, (b) air velocity, (c) relative humidity and (d) mean radiant temperature. All of which contribute to the thermal comfort in interior spaces. Several studies had been done and in the present investigation, the comfort zone in hot humid is in the range of 25^{o}C to 28^{o}C has been used [9, 10].

Measuring equipments such as the globe thermometer, sling hygrometer, anemometer as well as the CET Nomogram shall be used for this purpose. The internal surface temperature of the mosque roof membrane structure shall be measured with thermal imager to capture the range of temperature. This is to determine how much heat gain is associated with the roof as well as the confining walls and floor. In this study, thermal indoor conditions for different locations inside the mosque were monitored over a period of time.

The collections of site data are required to determine the thermal comfort inside a building. These processes are both time consuming and expensive and its reliability is often restricted to the specific time and areas being monitored. In order to keep the collection of site data to a minimum while at the same time evaluating thermal comfort across as much of the building as possible, Energy Plus® software was used in this study for predicting air temperature distribution inside the buildings. The software had been validated by many researchers to study thermal comfort performance inside the building as cited by Imran and Baharun [12].

2. The basic characteristics of the Mosque

The main focus of this study was to investigate the factors affecting thermal comfort of users in the mosque, which claimed had been constructed using new technology. The mosque is located at Kota Samarahan, Sarawak at latitudes 1.45° North and 110.5° East was selected. Figure 1 shows the front view of the mosque. This mosque adapted the modern design by using 'teflon' tensile membrane and hexagon shape as the structural design. The roof is made of PTFE coated glass fabric. The outstanding features of Islamic design could be seen by using the ornament glass for windows and doors features.

The basic elements of the mosque design as well as the activity modes occurring in a mosque shall be discussed before investigating the thermal indoor conditions in this selected mosque. One side of the hexagon is oriented towards the direction qiblat of the holy mosque in Makkah city and includes the mimbar which is commonly an elevated floor. These basic elements are the essentials of mosque design. Though the functions of the mosque have remained unchanged, its architectural form, space, construction system, and building materials have evolved and developed to a significant and variable extent in different parts of the Islamic world, influenced by many factors.

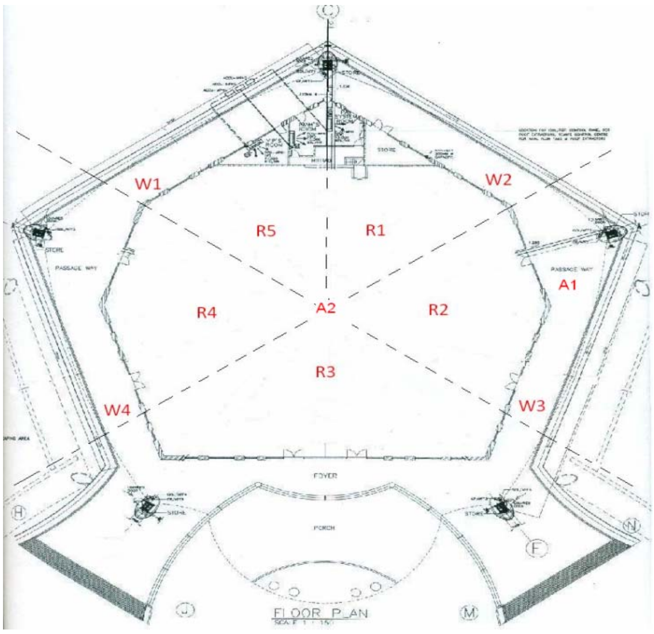
The mosque design is mainly influenced by worship considerations namely the prayer mode that performed with worshippers standing, bowing and prostrating. At certain occasion, people are seated on the floor in focus on the imam preaching or delivering the khutba while he is standing on the elevated mimbar floor. The mimbar normally located two meters above floor level but varies for different mosque.

Figure 1. Front view of Masjid Al Muttaqin Kota Samarahan

3. Assessment of thermal comfort condition

Air temperature, air velocity, relative humidity and MRT were measured during empty and fully occupied conditions. The positions of the measurement points for data collections to determine the level of thermal comfort were located according to ASHRAE [5] which specifies that the height for evaluating comfort should be 1.5m above the floor level. This height is reasonable for standing during performing prayers. In order to assess the thermal comfort conditions inside each mosque especially during prayer times, temperature and humidity measuring instruments were set hourly.

The positions of the node points used for data collections for surface, indoor and outdoor air temperature measurement shown in Figure 2. Data collected at these node points were also used to determine the level of thermal comfort in the mosque. However, due to the massive data recorded the analyses were selected based on the critical hours and scenario captured during period of study.



Legend:
R1 = Roof 1
R2 = Roof 2
R3 = Roof 3
R4 = Roof 4
R5 = Roof 5
W1= Wall 1
W2= Wall 2
W3= Wall 3
W4= Wall 4
A1 = Outdoor temperature
A2 = Indoor temperature

Figure 2. The location of surface, indoor and outdoor temperature measurement

As mentioned by most of researchers, comfort zone in Malaysian climate is in the range 25^{o}C to 28^{o}C. These values are superimposed in the graph shown in Figure 3 for purposes of comparison.

The data shows that the roof surface temperature fluctuated and could reach up to 45^{o}C during mid-day. The roof membrane with U-Value 5.6 W/m^{o}C is the only element separating the indoor and outdoor environment. The emissivity of roof material is 7.7%. However the solar reflectance of the roof materials is 71%.

Temperatures observed on most of the surfaces were exceeding the limit of comfort zone and only at 6 p.m., the temperature start reaching the comfort zone area. Direct solar radiation falling on the outside roof surface was rapidly absorbed causing high external surface temperatures. The heat transferred through the roofing material and which radiated into the area below. Mean radiant temperatures (MRT) and air temperature were higher in the mosque caused by higher surface temperatures especially under the roof.

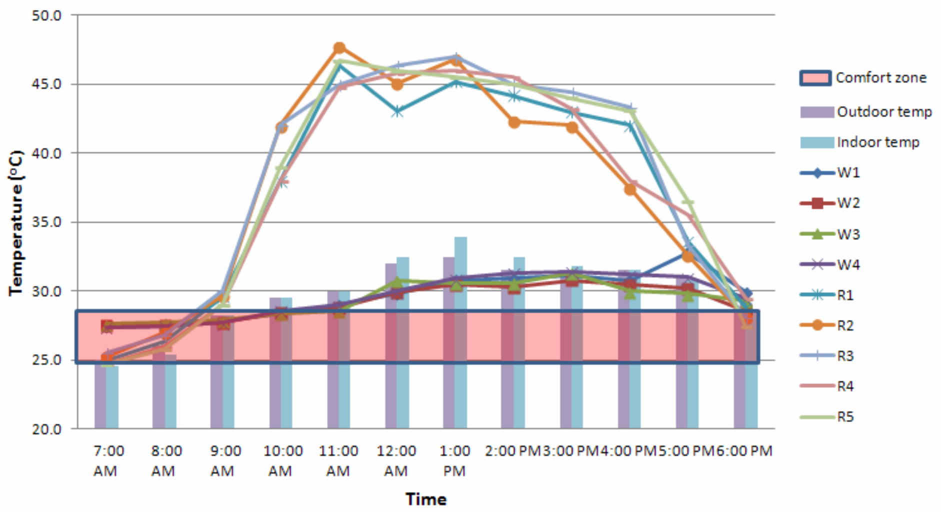


Figure 3. Surface temperature of the mosque

Figure 4 shows that the air temperatures exceed 30°C over most of time until 5 pm and the air velocity in the mosque is very low within the range 0.10-0.23 and the highest is only 0.37 m/s. Relative humidity is observed to be within acceptable comfort limits for most of the day with a slight increase beyond the upper limits towards the end of the day.

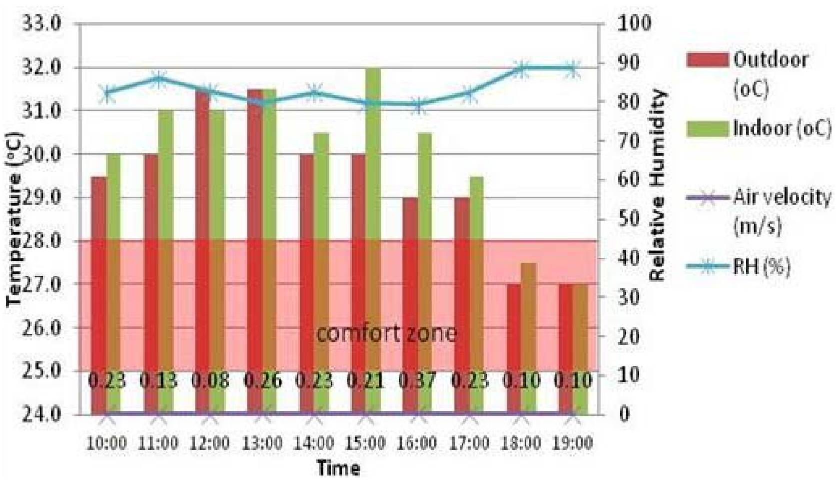


Figure 4. Outdoor, Indoor temperature, air velocity and relative humidity measurement data

Although the air velocity in the mosque is within the desired range for tropical climates [6], due to the higher air temperatures, thermal comfort is not achieved. Figure 5 shows that CET values are above the limit for comfort. The CET values shown were calculated using the air velocity and respective air temperatures at points.
The thermal images of roof surfaces, concrete structure and glazing area around 12 noon and 6 pm was captured using Thermal digital camera as shown in Figure 6. The surface temperature for roof and glazing area could reach 38°C compared to concrete structure which temperature is around 29°C. However, after 6 pm the roof temperature decreased to 24°C with difference 14°C. Glazing area surface temperature decrease around 8°C and brick walls retain the temperature around 29°C. Result from the thermal images shows that concrete structure had the capacity to store heat and the overheated roof surfaces was due to the direct solar radiation without any shading devices.

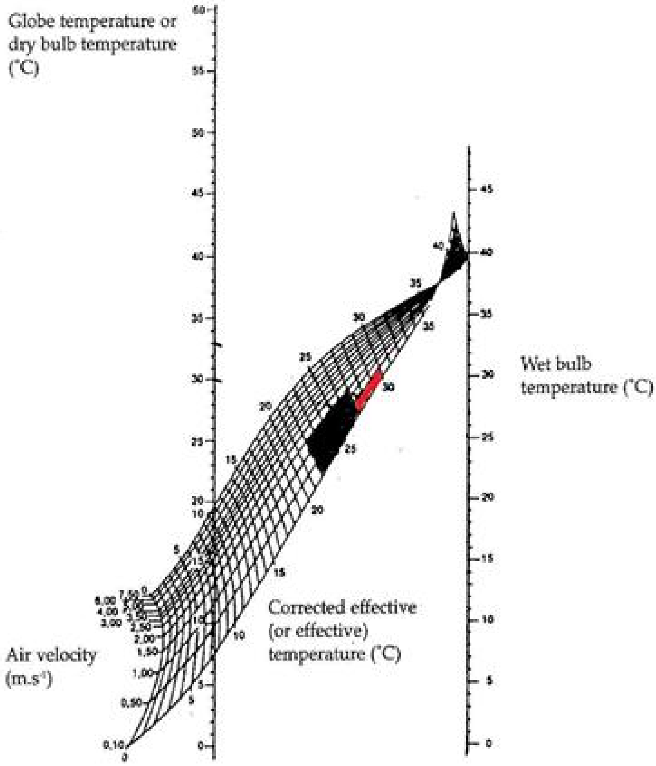


Figure 5. Corrected Effective Temperature inside the mosque

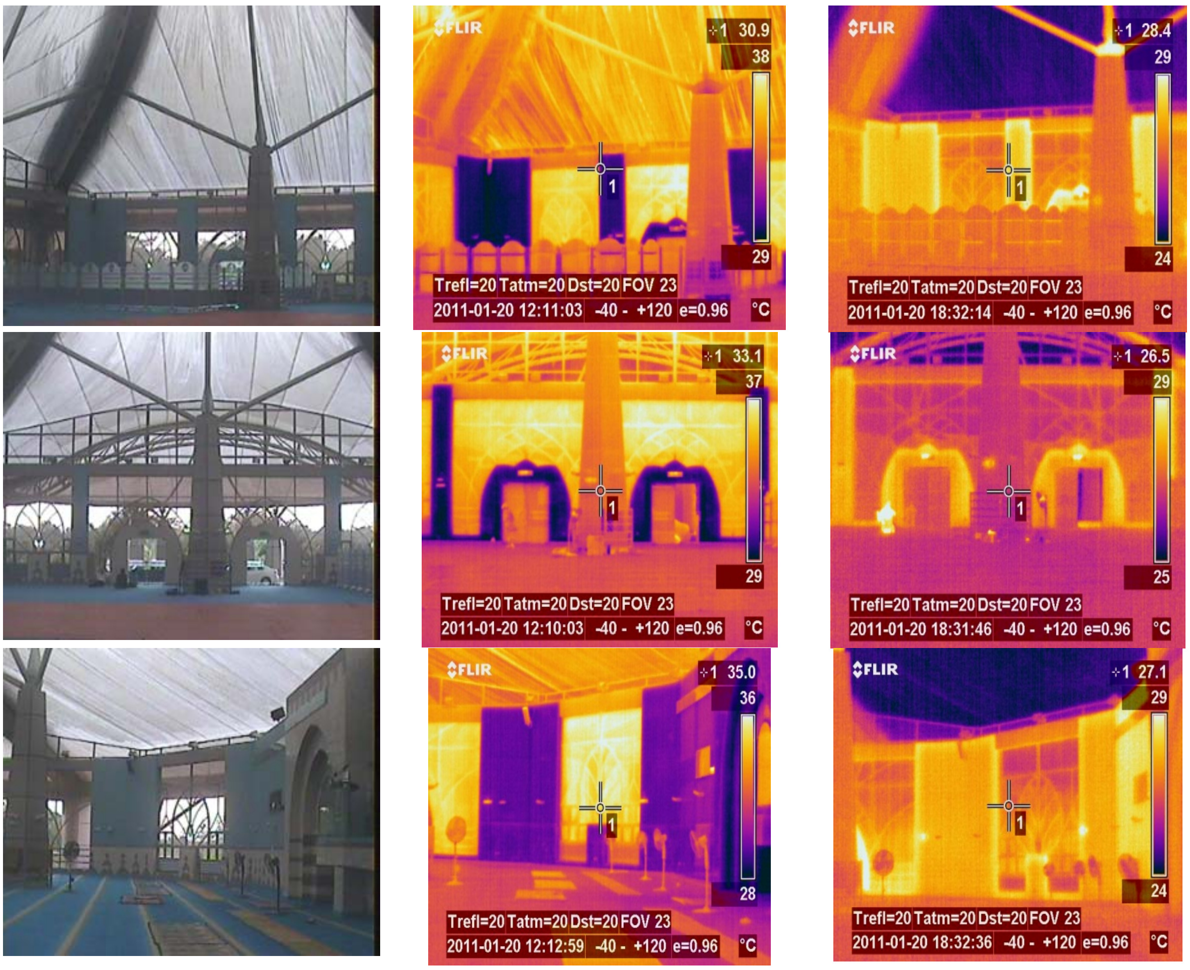


Figure 6. the thermal images of different surfaces at 12 noon compared to 6 pm

To overcome the thermal comfort problems that exist in the current mosque, a retrofit design are proposed by adding new materials and installing insulations on the existing roof. The existing mosque was taken as the basecase for comparative purposes. The designs were evaluated by adding and installing the following features as shown in Figure 7:

i. coating paint on the PTFE fiberglass roof membrane
ii. thermal radiant barrier
iii. install rockwool layer
iv. fibrous plasterglass ceiling

Figure 7. Proposed insulation materials for the roof

A simulation using Energy Plus® was carried out. The inside air temperature showed a distinct improvement with insulation when compared with the original design which devoid of insulation. It was hoped that the modified design would make additional improvements to comfort levels when air ventilation is provided. To check the extent of any improvement, another simulation was carried out.
The existence of air ventilation helps to decrease the air temperature inside the mosque. The improvement in air temperature is illustrated in Figure 8. From the simulations it can be seen that it is possible to improve the comfort conditions inside the mosque by adding insulation and providing air ventilation to an existing design.

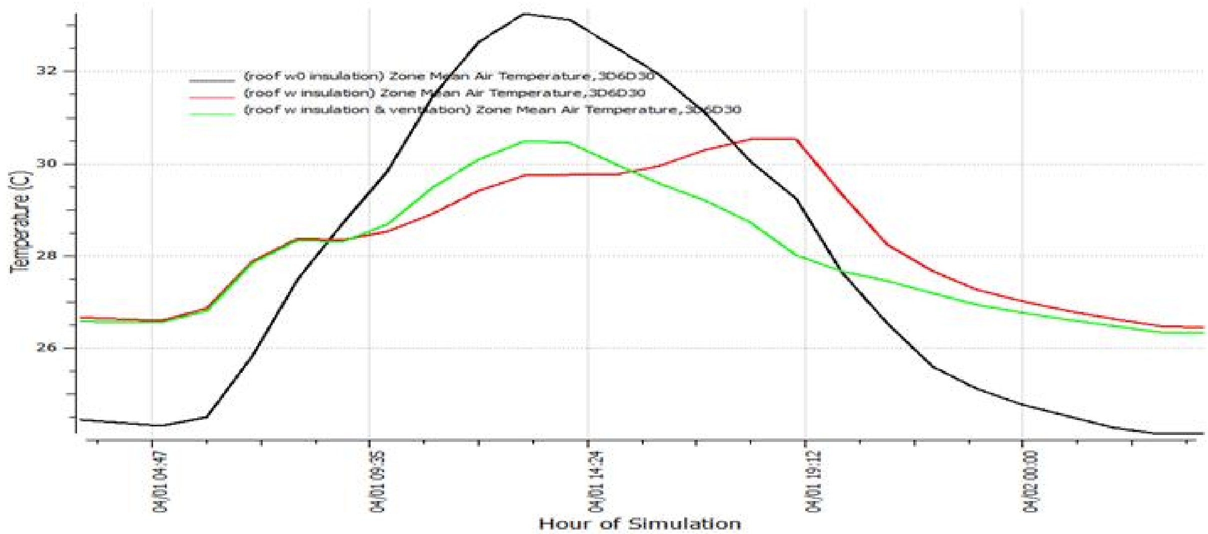


Figure 8. Simulation data shows the improvement of internal air temperature by implementing the retrofit design

4. Conclusion

The data collected during the field studies established that thermal comfort was not achieved in the mosque most of the time. The major cause for discomfort is the overheated by the heat entering into the building through the roof. The roof surface could reach up to 45°C during daytime and temperatures observed on most of the surfaces were exceeding the limit of comfort zone. Direct solar radiation falling on the outside roof surface was rapidly absorbed causing high external surface temperatures. The heat transferred through the roofing material and which radiated into the area below which caused discomfort to the occupants.

Result from the thermal images shows that the overheated roof surfaces were due to the direct solar radiation without any shading devices. The simulations data shows that the problems could be solved by adding insulation and providing sufficient air ventilation. Acceptable thermal comfort conditions can be enhanced by using thermal insulation. Good insulator provided under the roof gave provide good environment for the people occupancy.

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References

[1] Al-Homoud,M.S., Adel A. A., Ismail M. B., (2009) Assessment of monitored energy use and thermal comfort conditions in mosques in hot-humid climates, Journal Energy and Buildings 41, pg 607-614

[2] Saeed,S.A.R, (1996),Thermal comfort requirements in hot dry regions with special reference to Riyadh, Part 2: for Friday prayer, International Journal of Ambient Energy 17 (1) (1996) 17-21.

[3] Evan, M. (1980) Housing, climate and comfort. The Architectural Press London, Halsted Press Division, John Wiley and Son, New York

[4] Humphrey, M.A., (1992) Thermal comfort requirements, climate and energy. Proceedings 2nd WREC Conference. Reading, Pergamon Press. Pp 1725-1734

[5] ASHRAE Standards, (1992) Thermal environmental conditions for human occupancy. ASHRAE 55-92, Atlanta, USA.

[6] Karyono, T.H.,(1996) Thermal Comfort in the Tropical South East Asia Region, Architectural Science Review, Vol 39

[7] Szokolay S. V., (1990) Design and research issues : passive control in the tropics. Porc. First World Renewable Energy Congress. p 2337-2344, Reading U.K.

[8] De Dear, R.J., K.G. Leow (1990) indoor climate and thermal comfort in high-rise public housing in a equatorial climate: A field study in Singapore, Vol 24 B, No2, pp 313-320.

[9] Hanafi, Z. (1994) A comparison of traditional Malay house and modern housing design in relation to environmental comfort. Bulletin HBP, Penang, Malaysia.

[10] Ibrahim, S.H.(2004). Thermal comfort in low-income housing in Malaysia, PhD thesis, University of Leeds, UK

[11] ASHRAE Standards, (1992) Thermal environmental conditions for human occupancy. ASHRAE 55-92, Atlanta, USA

[12] Imran, S and Baharun, A (2011) Empirical Validation of Energy Plus Semi Detached Building Heat Gain Model, Proceedings of EnCon2011 4th Engineering Conference Kuching, Sarawak, Malaysia

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