URBAN MORPHOLOGY TO MINIMIZE SOLAR INSOLATION ON OUT DOOR URBAN SPACES IN THE TROPICS

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ABSTRACT. In the urban environment, a comfortable climate is important for well-being and to attract people to public spaces. Often the urban planning regulations and design concepts used in tropics ignore or poorly adapted to the local climate. As a consequence, urban areas often become unnecessarily uncomfortable as in Putrajayah new administrative center which experiences a 5^0C temperature rise compared to surrounding rural area. A similar office cluster design enclosing an outdoor plaza was proposed at Johor State New Administrative Center (JSNAC). Although, JSNAC is at construction phase, no studies have been conducted to evaluate the environmental impact on the outdoor spaces. This implies that solar prevention at the urban scale in the tropics is given little importance in planning and design process. Literature review suggests urban geometry and thermal properties of urban surfaces have been found to be the two main parameters influencing urban climate. This study develops a hypothetical concept of shadow umbrella using urban morphology for radiation reduction in the tropical outdoors during the day. Shadow umbrella concept largely depend on the solar geometry, therefore it is influenced by the bioregional climate conditions as well. This study emphasizes the effectiveness of the shadow umbrella concept in reducing the urban insolation using computer simulation models. To understand and to get the optimal ratio of the proportion, simulations have been done on different width and length of the plaza, height of the surrounding buildings and for different orientations of the plaza. The plaza in office cluster in Johor new administrative is later found to be oversized and inappropriately orientated. The results show that optimal ratio of building cluster geometry is 1: 1.5-2: 0.27-0.5 (W: L: H), which comply to shadow umbrella theory and proportion theories suggested by other researchers in this field.

INTRODUCTION

The equatorial climate has almost unchanging weather patterns throughout the year. Thus, living in the tropical outdoors is relatively pleasant for most of the year. Unlike other climates, daily weather patterns dominate over seasonal weather. It is described that all seasons occur within a single day here. According to Correa (1989) tropical living is a part indoors and part outdoor activities. Comfortable urban environment is important to attract occupants to public spaces. As such, shading to reduce the thermal stress and perceivable air movement to enhance the cooling effect are necessary in the outdoors.

Often the urban planning regulations and design concepts used in tropics are imported from temperate climates and thus did not fully respond to the characteristics of tropical climate. As a consequence, urban areas often become unnecessarily uncomfortable, such as in Putrajaya – a newly and carefully planned federal government administrative centre, has been experiencing a 5°C higher as compared to surrounding rural area. It was projected to reach up to 40°C, a contributing factor to global warming that brings about heavy rain and flash floods. Ahmad Fuad Embi, Drainage and Irrigation Department deputy director-general, in The Star News (March 6, 2007) explained a few contributing factors of the UHI phenomenon.

The office clusters at Johor state new administrative centre has a similar planning concept with Putrajaya. Office blocks in both designs are located enclosing a plaza. The orientation of the plaza is based on the symmetric planning layout rather than any environmental principles. According to Emmanuel (2005), inappropriate orientation and proportioned outdoor plaza will generate thermal discomfort in less-winded areas, especially in equatorial tropics. The proportion of the plaza will be analyzed and investigated. Below are the objectives of this research:

i. To investigate the current proportion of the plaza with literature review.

ii. To find out the shading angle and building geometry for the particular location of JSNAC by using the shadow umbrella theory.

iii. To find out the effectiveness of the existing plazas, based on solar insolation and shading percentage.

URBAN OUTDOOR COMFORT IN THE TROPICS

Urbanization and Outdoor Comfort. The shape of a city tends to trap radiation near the surface. A lot of energy is stored in the city during the day-time and it is then gradually lost during the night. This slows down the night-time cooling of a city compared to non-urban areas (ESPERE Climate Encyclopaedia, 2006). In view of this common phenomenon of Urban Heat Island in most of the major cities around the world, it has put increased demand on the comfort requirements in the design of buildings and outdoor environment (Khandaker, 2003).

Table 1. Key findings on ideal plaza in tropical climate

Research	Climate	Findings
Oke (1988)	Temperate (mid-latitude)	H: W ratio of 0.4 to 0.6,.
Emmanuel (1993)	Tropical	Hypothetical ‘shadow umbrella’ theory to create urban geometry based on sun position.
L. Shashua-Bar (2000)	Temperate	Highlighted the importance of urban geometry as shading and openness of the cluster to the sky (the Sky View Factor) to strengthen the outgoing of long-wave radiation.
Khandaker (2003)	Tropical	During early morning, open spaces or spaces with partial shading are desirable. In noontime, complete shading is required. During late afternoon, open fields or spaces with no enclosures are desirable.
Ahmed (2005)	Tropical	(W:L:H of 1 : 2 : 0.8). Best orientation is N-S
Yezioro (2006)	Temperate	(W:L:H of 1 : 1.5-2 : 0.6). Ideal orientation is N-S

Studies by Khandaker (2003) pointed out the problems of urban dwellers being inhibited to form any meaningful relationship with their present urban outdoor setting. Lifestyles are increasingly becoming introverted. This is due to the progressive degradation of the physical environment as an effect of urbanization. There are various effects of urbanization on climatic parameters. It is a microclimate change which will later influence the global climate.

Various studies and analyses were done on thermal effects of geometry and orientation of urban open space in different climate conditions, by different group of researchers (table 1). Geometry and thermal properties of urban surfaces had been found to be the two main parameters influencing urban climate (Oke T.R., 1987). Oke (1988) argued the role of the urban in terms of thermal comfort is to provide urban shelter, achieve warmth, maximize solar access and provide adequate natural daylighting.

Johor State New Administrative Centre. JSNAC, the most recently planned and built government administrative centre is located at 1.4°N, 103.7°E. The office planning approach found in Putrajaya and JSNAC is popularly termed as “office cluster”. However, the term “office cluster” is not yet a formal and general label for such approach. But the two main components which can be identified in this planning approach are the central plaza and the office blocks. The overall concept plan will have a vast focal open space, Dataran Mahkota. At both ends, stand the landmark buildings of Dewan Undangan Negeri and Menteri Besar’s complex, which is along the Qiblat Axis. There are 6 oval office clusters on the periphery in axis towards the Dataran Mahkota. Two office clusters were chosen as study areas, because of the different orientations.

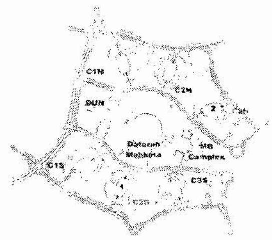

Figure 1: Overall plan of JSNAC and location of 2 study areas – 1 (C2S), 2 (C3N)

METHODOLOGY

The Plaza Investigation. The maximum allowable height is 37.8 m for the flexible unit and 31.8 m for the front blocks. In this study, height is considered fixed at the maximum allowable value. The changing parameters therefore are the width and length for this case. The width between the two office blocks is 98 m. The investigation work will be done by referring to the suggested aspect ratio from table 1, where simple calculation of the W: L: H will give a fast and early idea whether the plaza is in a good proportion.

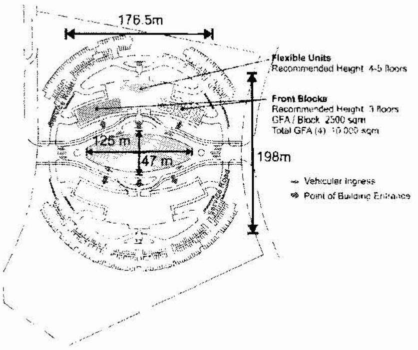

Figure 2: Site plan of the JSNAC office cluster

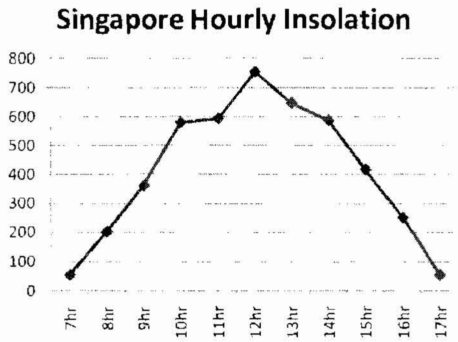

Figure 3: Hourly solar insolation of Singapore on 21 June

The data which will be used as a reference and for simulation purpose is Singapore, due to the location of JSNAC which is near to this neighbouring country. Recorded solar insolation of 21 June from 0800 hr to 1700 hr is 4519.85 W/m^2. The hourly solar insolation indicates that minimum temperature occur before 0700 hours and rapidly rise within the next three hours. By 1100 to 1200 hours, radiation gain reaches near maximum level and stays high until 1300 hr. It declines rapidly, starting at around 1400 hours.

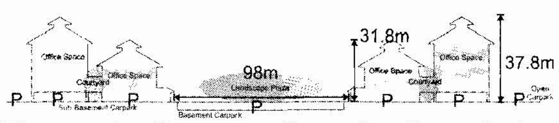

Figure 4: Cross section of office cluster, JSNAC and the canyon geometry

Shadow Umbrella. The decisive factor of shadow umbrella theory (Emmanuel, 1993) is to optimize shaded public outdoor spaces using urban build form. The ratio between the building height (H) and width (W) and length (L) of the open space is important and will be determined through this theory. Shadow umbrella concept largely depends on the solar geometry – the solar altitude and solar azimuth. This implies that it depends on some basic elements of the specific site: date of year, time of day, location, building orientation and dimensions.

The purpose is to shade a particular surface at all times, thus the lowest angles must first be established. The northernmost solar exposure occurs during the summer solstice (June 21). The southernmost exposure will be on the winter solstice (December 21). These two days will determine the northern and southern extremities of sun positions.

Figure 5: Shadow umbrella urban block

Figure 5 shows the ideal shadeable urban block developed from shadow umbrella theory for JSNAC (1.4°N, 103.7°E). It turns out that the block will be elongated along north/south, and has a proportion of roughly 1:2 (east/west: north/south). The height in the east will be 0.27 in ratio and 0.50 in the west.

Software Simulation Analyses. The software simulation analyses were carried out by using Ecotect software. Ecotect was a complete building design and environmental analysis tool that covers the full range of simulation and analysis functions required to truly understand how a building design will operate and perform. This included shading, solar, lighting, thermal, acoustics and so on. The definition of 'insolation' from Ecotect referred to incident solar radiation and represented the amount of radiation incident on a point or surface over a specified period. First overshadowing masks were generated at each point due to surrounding buildings and objects, hourly diffuse and direct radiation data was read directly from the climate data over a user-set period. Assessment of solar insolation and percentage of shading were done on both plazas of the study clusters to understand the average hourly solar insolation received on the plaza between the cut-off hours of 0800 hr to 1700 hr.

The studies were conducted on one day, representing the summer solstice which is 21st of June, as on 21st of June, the sun is at its northermost. It represented the lowest value of solar insolation (besides winter solstice on 21 December) of the year a tropical surface may experience. Singapore's weather data was used as data source because of the location of the site near to Singapore. Simulations were conducted on the real dimension and condition on site – the width, length, and height (maximum allowable height of 31.8 m, 37.8 m), and orientation which according to planned footprint of the office blocks and centre plaza. Lastly, simulations were conducted on a rectified proportion of the plaza (which is complying to the aspect ratio theory) to get the performance of the plaza.

ANALYSES & RESULTS

Plaza Proportion. The calculation of geometry in one of the office cluster uses the maximum allowed height given in the planning guideline and is divided by the width of the plaza. It is found to be slightly outside the suggested ideal figure by Oke (0.4 to 0.6). The plaza is slightly too wide exposed and in other words the geometry of the buildings are not able to generate desired shading to the space.

Solar Insolation. Located in the tropical area, the site is subjected to hot and humid climate, which solar radiation and heat as major climate threat. The use of green or nature as centre plaza in office cluster design will provide a comfortable public space and enhance working environment to the office. However, from the software simulations and analyses, a few problems or design errors are found.

Figure 6 shows the average solar insolation value of the plaza (area of analysis). There is no much difference even though the value of E-W orientation is higher. This graph suggests that the plaza is oversized. Heat will build up quickly at the early of the cut-off hour and goes down rapidly in the afternoon. It reaches the peak at the hour between 1200 hr and 1300 hr. The afternoon solar radiation is higher than morning.

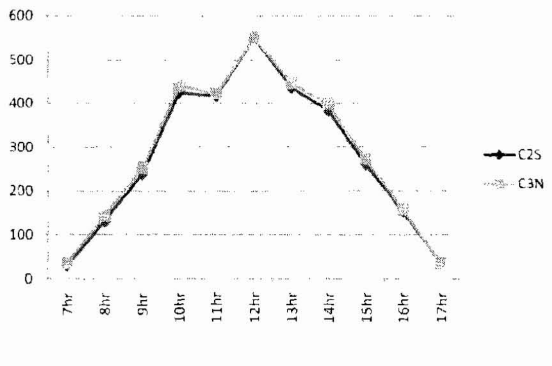

Figure 6: Average solar insolation (W/m^2) of plazas in C2S and C3N on 21 June

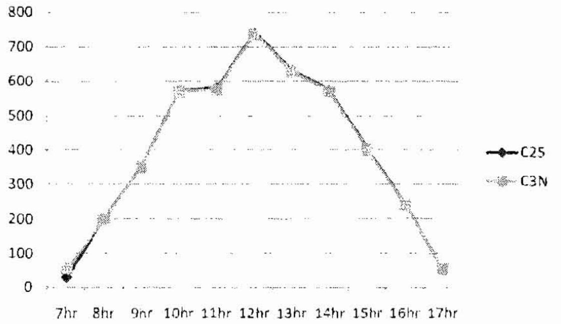

Figure 7: Solar insolation (W/m^2) in the center of plazas in C2S and C3N on 21 June

Figure 7 gives the spot reading taken in the centre of the plaza. The values are almost the same for both orientations. This graph suggests that no much shade available in the centre of the plaza throughout the day. The plaza is too large to be shade by the geometry of the building. There is a significant decrease in solar insolation reading (Figure 8) for the rectified proportion of C2S. It is found that the rectified plaza achieved a performance of 10.22% and 13.15% lower than C2S and C3N respectively in the solar insolation analysis. This suggests that the proportion of the plaza, i.e. aspect ratio is effective in reducing the solar insolation.

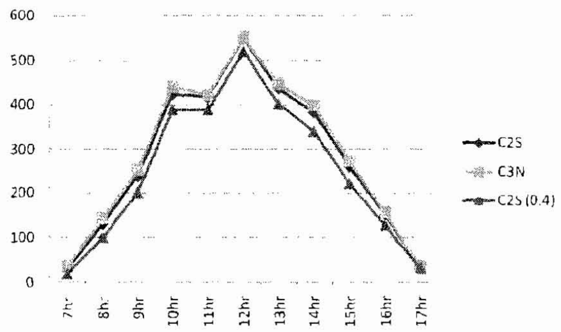

Figure 8: Rectified proportion of C2S according to Oke's theory and its solar insolation (W/m^2) performance

Shade Percentage. Figure 9 proved the plaza with NE-SW orientation (C2S) is better shaded, especially in the early of the day and in the late afternoon when the building blocks create shade for morning and afternoon sun. Up to 50% more shade during these hours of time in comparing to C3N. In average, C2S generates 27% more shade than C3N. Percentage of shade declines in the noon time. Although the percentage of shade in the afternoon is higher, the solar insolation is also higher in the afternoon (Figure 7), which means the average shading percentage and average solar insolations are not relative. This is because different areas are shaded or exposed to different level of solar radiation. West sun is severe in the tropics and is important to be avoided. The graph of early morning and late afternoon is in same pattern with the 2 study plazas, and both meet in the noon time where the plaza is oversized and shade is inadequate. The rectified proportion of C2S achieves 67% and 112.26% more shade than C2S and C3N. The rectified plaza shows significant shade even when approaching and during noon time.

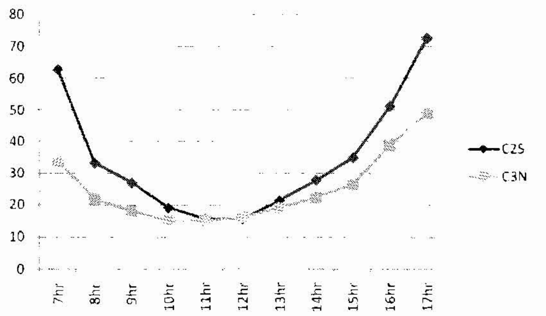

Figure 9: Percentage of shading in the plazas in C2S and C3N on 21 June

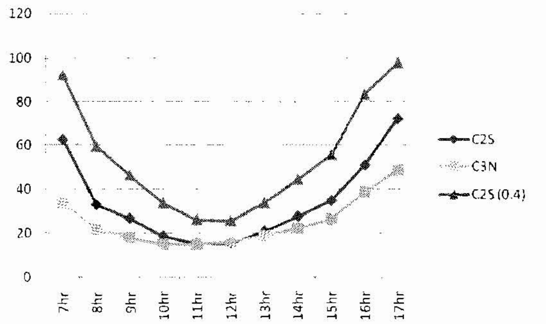

Figure 10: Rectified proportion of C2S and its shading (percentage) performance

Model from shadow umbrella. Figure 11 illustrates the ideal massing for C2S and its plaza developed from the shadow umbrella diagram. The plaza is elongated along north/south, and has a proportion of roughly 1:2 (width: length). The height in the east will be 0.27 in ratio and 0.50 in the west. The optimum courtyard ratio is defined as that allows the form to receive minimum radiation in the day and maximum radiation to be released at night. In short, the ideal proportion of urban geometry for office clusters in JSNAC is 1: 1.5-2 : 0.27-0.5.

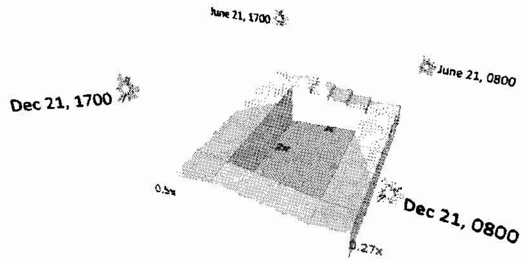

Figure 11: Model showing ideal proportion of urban built form for JSNAC

SUMMARY AND FINDINGS

From the analysis, it can be concluded that JSNAC experiences following problems;-

a. Oversized plaza – Low height to width ratio. This may lead to overexposure to heat and difficult in creating shade both to the plaza and building itself. On the other hand, the maximum allowable height of the buildings proposed by planners may have been too low.

b. The centre of the plaza is inadequate in shading. The plaza is too large to be shade by the geometry of the building.

c. There is no much difference in the value of C2S (NE-SW) and C3N (E-W) orientation. It is found that shade will only perform during noon time when the proportion of the plaza is ideal.

d. Although the percentage of shade in the afternoon is higher, the solar insolation is also higher in the afternoon. West sun is severe in the tropics and is important to be avoided. The ideal proportion of urban geometry for office clusters in JSNAC is 1: 1.5-2: 0.27-0.5 (W:L:H).

CONCLUSION

This study is generally to make the equatorial urban outdoors thermally comfortable. Although life in the equatorial region is largely an outdoor phenomenon, modern urban development which is lack of environmental concern during planning, has failed to facilitate such climatically pleasant outdoor environment. Solar radiation and heat are found to be the major problem. Various studies unanimously suggested shading to be major concern in tropical urban to bring comfort to the spaces. The planning of the office clusters in JSNAC, which incorporated a centre plaza, has the potential to be a cool and comfortable outdoor urban environment. However, through the plaza investigation and software analyses, the orientation, building geometry (height to width ratio of the plaza), proportion and size of the plaza are found to be inappropriate, too wide and overexposed to the solar radiation. This rises a question of 'will JSNAC become the next heated Putrajaya?' It is always better to prevent than to cure. In view of these problems, measure should be taken during the planning stage before the construction to solve the problems. Solution is developed by a shadow umbrella model of the specific JSNAC site, with ideal building geometries and proportion, to improve the existing design and to prevent the plaza from becoming a 'planned wasteland' or 'urban desert' because of heat. The results show that optimal ratio of building cluster geometry is 1: 1.5-2: 0.27-0.5 (W:L:H).

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