Bioclimatic Performance of High Rise Office Buildings: A Case Study in Penang Island

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ABSTRACT: It is frequently argued that bio-climatic design strategies result in substantial energy savings in buildings and higher levels of user's satisfaction. Such claims have not been fully substantiated by systematic research, however, particularly when dealing with high rise office blocks [i]. This paper presents the performance of a high rise bio-climatic office block designed by Ken Yeang and compares it with that of a conventional one. Both case study buildings are located in the Island of Penang, Malaysia with similar outdoor conditions. Indoor environmental parameters have been measured using portable equipment and user's perceptions have been recorded using structured questionnaires. The paper presents the rating of a comparative analysis of the measured indoor temperature and user's perception in both office buildings.

Keywords: Bioclimatic, High-rise office, Tropical Climate, Comfort, Users' satisfaction

1. INTRODUCTION

High rise buildings have been proliferating in major cities in Malaysia since the 1960's. In the 1970's, Ken Yeang proposed a set of bioclimatic principles for high-rise buildings in tropical climates [ii].

This paper presents the ratings of an evaluation of the performance of two different types of high rise office blocks: one "conventional", the other incorporating "bioclimatic" principles. Both buildings are located in the city of George Town, Penang, Malaysia. A series of building design evaluations has been carried out in a systematic way in order to test the following assumption: "Bioclimatic buildings create a better working environment for the users and provide higher level of satisfaction than conventional ones".

The evaluation of the two building types was carried out in relation to the quality of lighting, ventilation and thermal comfort in the office spaces of each of the case study buildings.

2. RESEARCH METHOD

Field work was carried out in Malaysia in July 2004 during which questionnaires were distributed to the occupants in two different office buildings in order to record their perceptions of the environmental qualities of their working space [iii]. The collection of subjective data (recording the perception of the office space by its occupants and their level of satisfaction) allowed for a subjective data analysis.

Direct observations were carried out by the authors on various architectural aspects of the buildings attributes. A project checklist was developed to indicate elements related to environmental design strategies.

Indoor air temperature and air velocity were measured at a selected floor in each zone (lower, middle and upper) where the questionnaires were distributed. Measurements were taken on an hourly basis and at several points in the respective floor areas.

The user's satisfaction data was gathered via questionnaires which were distributed to the building occupiers, mainly in the open plan office spaces. In the questionnaire, respondents were asked to give their opinion on the architectural and environmental qualities of their building. They were also required to express their level of satisfaction with the lighting, ventilation and thermal comfort in their particular office space. The sample consisted of a third of the occupants. A reasonable number of questionnaires were distributed randomly to the staff and those returned were about 35% of the total distributed.

3. CASE STUDIES

The user's satisfaction data was gathered via questionnaires which were distributed to the building occupiers, mainly in the open plan office spaces. In the questionnaire, respondents were asked to give their

Two buildings were involved in this study: the Tun Abdul Razak Complex (conventional) – more popularly known as KOMTAR Tower and the United Malay Union Organisation building (bioclimatic) – known as UMNO Building (see figure 1).

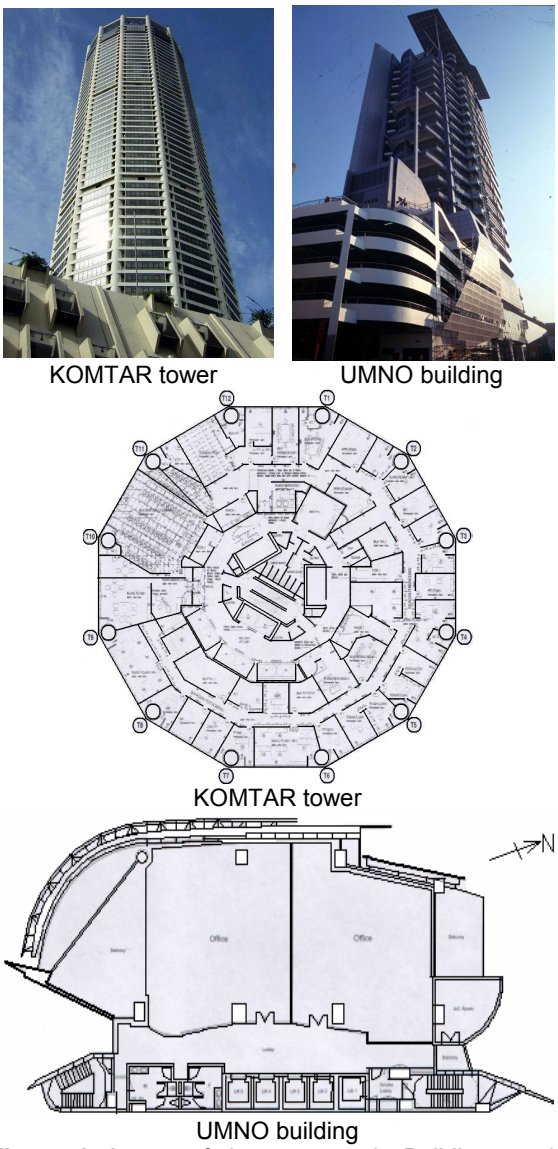


Figure 1: Image of the case study Buildings and typical layout plan of the buildings

The buildings are located in Penang Island, among the most developed state in the Northern region of Peninsular Malaysia, situated at latitude 5°26'N and longitude 101°42'N. The climatic characteristics can be classified as warm-humid equatorial with high temperature and humidity through out the year, intense sunshine, strong glare, high radiation levels and rainfall [iv]. The average outside air temperatures is between 25°C and 34°C with relative humidity ranging from 80% to 90% percent. Winds are generally of low-variable speed but can be strong when combined with rain. Rainfall averages 2500mm to 3000mm annually and is more intense with the monsoons [v].

The KOMTAR building is the landmark of Georgetown, Penang, consisting of a tower block of 68 storeys and a huge shopping mall below. The KOMTAR building, designed by Lim Chong Keat in the 1970s is made of 12 similar-sided polygons that look almost circular from afar [vi].

The UMNO building was designed by T.R. Hamzah & Yeang Sdn Bhd in 1998 and is about 1/3 of the size of KOMTAR. The site has an area of about half acre and it is within 15 minutes walking distance of KOMTAR in Penang Road. The 21-storey building contains spaces for Banking Halls on the ground floor and at Level 1, and an auditorium for meetings and assemblies at Level 6. The Auditorium is also accessible by a separate external staircase. Above this are 14 floors of office space [vii].

4. RATINGS

4.1. Characteristic of the Respondents

All together, 59-office staffs were involved in the study with 2/3 from KOMTAR tower and 1/3 from UMNO building. The respondents' age ranged from 20 to 56 years where the majority 45.8% of the respondents were between 20 to 29 years old. Malay ethnic represented 79.3% of the total respondents in both buildings, followed by Chinese 13.8% and Indian 6.9%.

The thermal resistance value of clothing (clo value) for all respondents was calculated. The maximum for both KOMTAR tower and UMNO building is 0.93 and 0.99 respectively whereas the minimum clo value for both buildings is 0.54. The average clo value for both buildings differs by 0.03: 0.65 in KOMTAR tower and 0.68 in UMNO building.

The level of occupants' activity in the office spaces varies from reading, sitting, writing, typing, filing and walking about. Therefore the metabolic rate varies from 1.0 to 1.7 with an average metabolic rate of 1.23 [viii].

4.2 Observation of Architectural Design

Based on the bioclimatic indicators for high rise block [ix], [x] and observation during the field work, there were thirteen bioclimatic features identified in UMNO building whereas only four were found present in KOMTAR tower, as shown in table 1.

In UMNO building, all building services such as lift, toilet, staircases, utilities duct (building service core) are grouped and are all located along the east facade. Being elongated, the building allows for good cross ventilation and presents a North West- South East orientation. There are wind wing walls located on the west side of the building. These external walls have parts that control and enable good cross-ventilation for internal comfort, provide solar protection, regulate wind-driven rain and facilitating rapid discharge of heavy rainfall. The bioclimatic approach also provides buffer zones through carefully located building services which insulate the internal spaces while at the same time minimizing air-conditioning loads.

In KOMTAR tower, however, the service core is located in the centre of the polygon shape of the building and the geometry of the site does not coincide with sun path geometry. Most of the windows are facing towards the panoramic views of the island but exposed directly to the full impact of

external temperatures and radiant heat especially on the east and west sides.

4.3. User's Perception of their Building Design

This section presents user's perception of the quality of several aspects of building design and their satisfaction level with them. Perceptions were measured using several rating scales in the survey as shown in table 2.

Table 1: Bioclimatic indicators for high rise buildings in UMNO building and KOMTAR tower.

INDICATORS \ BUILDING	UMNO	KOMTAR
Bioclimatic Strategies		
Plan/Use patterns/ ventilation	√	
Balconies and terraces	√	
Site/Building solar sky-court	√	
Environmentally interactive wall	√	
View out from lobby	√	
Site building adjustment	√√	√√
Curtain wall at N & S facades	√	
Form and Envelope		
Shading devices	√	
Wind ducts	√	
Wind scoops	√	
Insulative wall	√	√
Cores at hot side	√	
Central core		√

Table 2: Several rating scales used in the survey

negative			neutral	positive		
-3	-2	-1	0	1	2	3
Hot	Too Warm	Slightly warm	Comfortable	Slightly cool	Cool	Very cold
Much too dim	Too dim	Slightly dim	Just nice and clear	Slightly bright	Too bright	Much too bright
Much too breezy	Too breezy	Slightly breezy	Just right	Slightly still	Too still	Much too still
Highly satisfied	Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied	Highly dissatisfied
	Poor	Fair	Adequate	Good	Excellent	

4.3.1 Architectural Design

Twenty nine questions related to architectural design were asked in the questionnaires such as quality of window size and position, general layout, corridor, sky court, adequacy of spaces, terraces and etc. Out of twenty nine, 20 questions have rating frequency skew towards "positive" categories and 9 questions have ratings frequency skew towards "negative" categories for KOMTAR tower. Whereas in UMNO building, 22 questions have ratings frequency skew towards positive categories, 6 questions have rating frequency skew towards "negative" categories and 1 "neutral".

Elements that skewed towards negative categories for KOMTAR tower are: (1) adequacy of space, (2) flexibility of space use, (3) availability of parking space, (4) lift lobby pleasantness, (5) public amenities in washrooms, (6) quality of safety and security system, (7) lift service interval time, (8) satisfaction of overall lift services and (9) difficulty in closing/opening window.

Elements that skewed towards negative categories for UMNO building are: (1) quality of landscaping at most common area, (2) lift lobby pleasantness, (3) public amenities in washrooms, (4) lift service interval time, (5) satisfaction of overall lift services and (6) windows' position.

A summary of the rating for architectural elements is shown in Figure 2.

4.3.2 Ventilation

Fifteen questions related to air ventilation condition were asked in the questionnaires such as availability of natural ventilation at work stations, meeting areas and corridors as well as the quality of air circulation from the air conditioner at lift lobby, rest rooms, etc. Out of fifteen, 4 questions have rating frequency skew towards "positive" categories, 10 questions have rating frequency skew towards "negative" categories and 1 is "neutral" for KOMTAR tower. While in UMNO building, 4 questions have rating frequency skew towards positive categories and 11 questions have rating frequency skew towards "negative" categories.

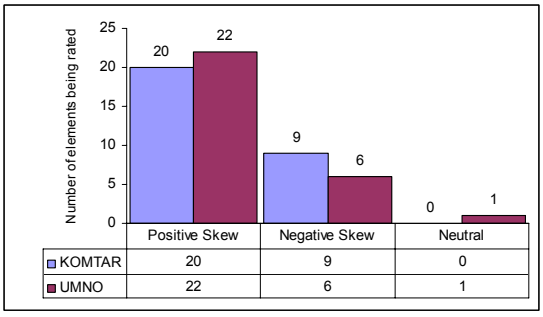


Figure 2: Distribution rating for architectural condition

Elements that skewed towards negative categories for KOMTAR tower are quality of natural ventilation available at: (1) workstation, (2) lift lobby, (3) meeting area, (4) restroom, (5) corridor; quality of air conditioner air circulation available at: (6) lift lobby, (7) meeting area, (8) corridor; (9) satisfaction towards quality of odour in washroom and, (10) overall air movement from air conditioner in office.

Elements that skewed towards negative categories for UMNO building are quality of natural ventilation available at: (1) workstation, (2) meeting

area, (3) restroom, (4) corridor; (5) overall satisfaction with the natural ventilation available in the office; quality of air conditioner air circulation at: (6) lift lobby, (7) meeting area, (8) rest room, (9) corridor, (10) satisfaction towards quality of odour in washroom and, (11) overall air movement from air conditioner in office. Summary of the rating for ventilation elements is shown in Figure 3.

Figure 4 shows the hourly air velocity reading for both KOMTAR tower and UMNO building. The daily air velocity in KOMTAR tower in average is 0.07 ms^{-1} with minimum and maximum of 0.04 ms^{-1} and 0.09 ms^{-1} respectively whereas in UMNO building, the daily air velocity in average is 0.10 ms^{-1}, slightly higher than that of KOMTAR tower with minimum and maximum of 0.05 ms^{-1} and 0.16 ms^{-1} respectively.

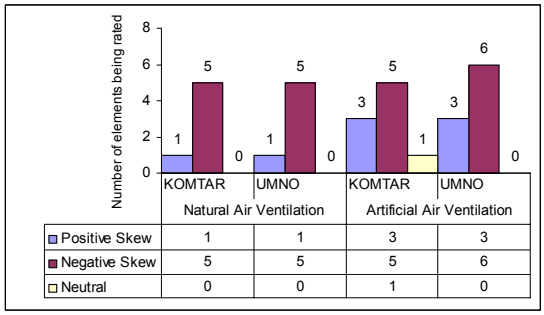


Figure 3: Distribution rating for ventilation condition

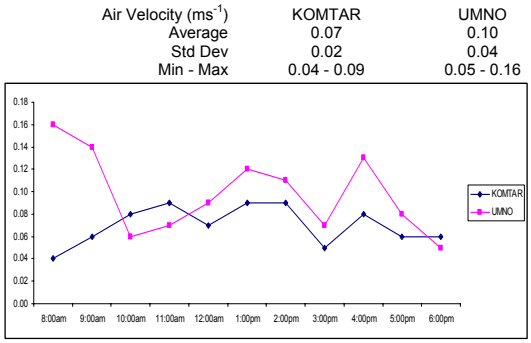


Figure 4: Air velocity (daily average)

4.3.3 Thermal Comfort

Users' perception of the thermal comfort of their working space was assessed through their rating of seven questions such as quality of thermal comfort at their work station, lift lobby, meeting area, rest room, and corridor. The overall perception of thermal comfort within the building was also recorded.

Out of seven, 4 questions have rating frequency skew towards "positive" categories, 2 questions have rating frequency skew towards "negative" categories and 1 question is "neutral" for KOMTAR tower. Quite similar in UMNO building where 4 questions have rating frequency skew towards positive categories and 3 questions have rating frequency skew towards "negative" categories.

Elements that skewed towards negative categories for KOMTAR tower are: (1) quality of the temperature level at corridor and (2) overall thermal sensation at the office whereas those for UMNO building are: the quality of the temperature level at: (1) work station, (2) lift lobby and (3) rest room. Summary of the rating for thermal elements is shown in Figure 5.

Figure 6 shows the hourly air temperature reading for both KOMTAR tower and UMNO building. The daily indoor temperature in KOMTAR tower in average is 24.6°C with minimum and maximum of 23.8°C and 25.2°C respectively whereas in UMNO building, the daily indoor temperature in average is 22.7°C, slightly lower than that of KOMTAR tower with minimum and maximum of 21.4°C and 24.4°C respectively.

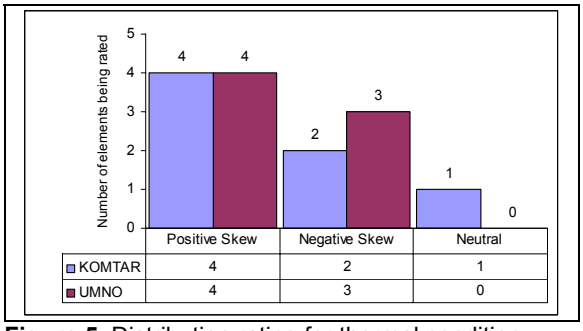


Figure 5: Distribution rating for thermal condition

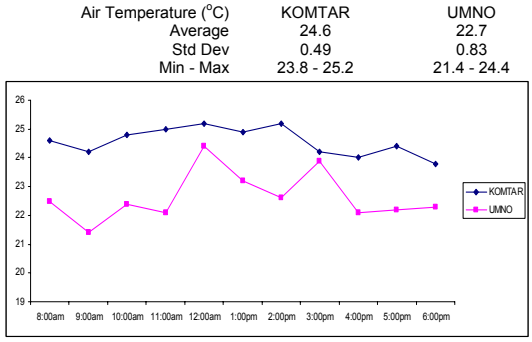


Figure 6: Air temperature (daily average)

4.3.4 Lighting

Fourteen questions related to lighting conditions were assessed in the questionnaires such as availability of natural light at work station, meeting area, corridor, quality of artificial lighting at lift lobby, rest room and etc. Out of fourteen, 13 questions have rating frequency skew towards "positive" categories and only 1 question has rating frequency skew towards "negative" for KOMTAR tower whereas in UMNO building, 10 questions have rating frequency skew towards positive categories, 3 questions have rating frequency skew towards "negative" categories and 1 "neutral". Elements that skewed towards negative categories for KOMTAR tower is the quality of natural light available at lift lobby whereas for UMNO building are the quality of natural light available at: (1) meeting area, (2) rest room and (3) corridor. Summary of the rating for lighting elements is shown in Figure 7.

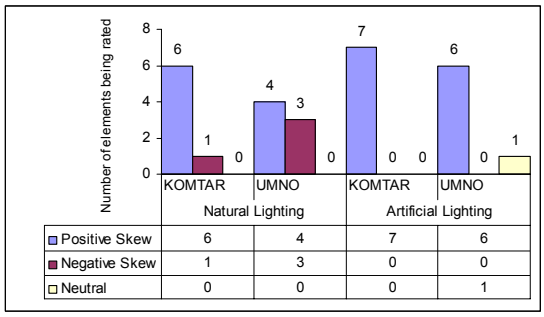
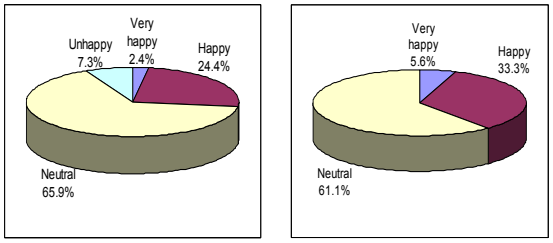


Figure 7: Distribution rating for lighting condition

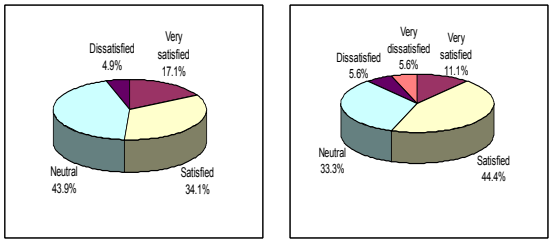
4.3.5 Overall Working Environment Condition

Most respondents gave positive indications relating to satisfaction with their working environment in both KOMTAR tower and UMNO building, with majority ratings of 51.2% and 55.6% respectively. About 43.9% of respondents rating for neutral in KOMTAR tower whereas in UMNO building is 33.4%. Figure 8 shows the Frequency for working environment satisfaction in pie chart diagram. Most of the respondents are happy working in their building. None of the respondents in UMNO building are unhappy but 7.3% of respondents in KOMTAR tower are unhappy working in their building as shown in Figure 9.



KOMTAR tower UMNO building

Figure 8: Rating frequency for working environment satisfaction



KOMTAR tower UMNO building

Figure 9: Frequency of overall satisfaction ratings with the working environment

5. DISCUSSION

All together 65 elements were rated by the respondents in the questionnaires in order to record user's perception of several features in their building as well as their satisfaction level with those features. Out of the 65 elements being evaluated in KOMTAR tower, 41 elements have rating frequency skew towards "positive" categories, 22 elements have rating frequency skew towards "negative" categories and 2 elements are "neutral". While in UMNO building, 40 elements have rating frequency skew towards positive categories, 23 elements have rating frequency skew towards "negative" categories and 2 elements are "neutral". The distribution is summarised in Figure 10.

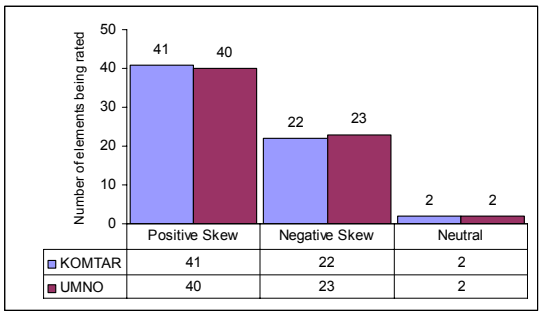


Figure 10: Distribution of ratings for all evaluation components

In architectural design, UMNO building has more elements falling into positive categories than that of KOMTAR tower. This could be related to the bioclimatic strategies approaches applied in the building that provide significant impact on the quality of architectural design as there are about thirteen bioclimatic criteria found present in UMNO building as mentioned in section 4.2.

UMNO building is probably the first high-rise office that uses wind as natural ventilation at point of entry as a source of fresh air-supply to the interior and not for internal comfort. All the lift lobbies, staircases and toilets also have natural ventilation making the building have higher level of air-change per hour. This criterion is not available in KOMTAR tower and that might be one of the reasons why the indoor air velocity in UMNO building is slightly higher than that of KOMTAR tower (see Figure 4). However the human factors analysis via questionnaires does not agree with the measurement data where most of the elements related to air ventilation condition fall into negative categories for both KOMTAR tower and UMNO building (see Figure 3).

The polygon shape of KOMTAR tower has no external shading devices to minimize solar heat gain whereas the UMNO building has wind wing-walls (see figure 1) that direct wind to special balconies zone and at the same time minimize solar heat gain from external wall. This might be why the indoor air temperature in KOMTAR tower is slightly higher than that of UMNO building (see Figure 6). But, the human factors analysis via questionnaires for both building has quite similar rating (see Figure 5).

As for the lighting condition especially the natural lighting, KOMTAR tower has more elements fall into positive categories than that of UMNO building. It might be due to the various orientations of each polygon side when they are exposed to direct sunlight whereas in UMNO building only three sides are being exposed (see figure 1).

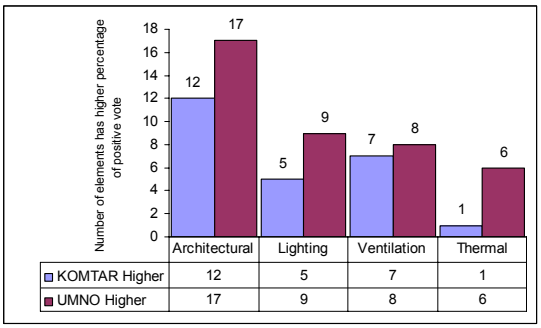


Figure 11: Higher percentage of positive rating for all elements in both blocks.

6. CONCLUSION

It can be concluded that the claimed advantage of "bioclimatic high rise office building creates a better working environment for the users and provides higher level of satisfaction than conventional ones" is clearly substantiated. In order to substantiate the hypothesis further, more similar investigation should be done in the future. Application of computer programs available in the market might be useful to proof the claim advantage in more precise technique. Software package such as Ecotect and ASHRAE Thermal Comfort program or others simulation based program can be used to analyse the data for a particular area. At the moment, the authors are processing similar investigation on another four buildings that have similar characteristics in order to provide more evidence to substantiate the hypothesis.

From the environmental measurement rating, we found that all elements indicate that bioclimatic design has better indoor environment than that of a conventional one however, based on user's perception from the survey data, there were no clear advantages in building performance in either "bioclimatic" or "conventional" high rise building.

However if we specifically focus on the positive ratings alone and compare the rating percentage between KOMTAR (conventional) and UMNO (bioclimatic) we can see that out of 65 elements, 40 elements show that UMNO building has a higher percentage of positive ratings whereas KOMTAR tower has only 25 elements higher percentage than that of UMNO building (see figure 11).

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