Bioclimatic Technology in High Rise Office Building Design: A Comparison Study for Indoor Environmental Condition

[1]. Lokman Hakim Ismail, [2.] Magda Sibley and [3.] Izudinshah Abdul Wahab

[1] Department of Construction Engineering and Architecture, Faculty of Civil and Environmental Engineering, University Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

[2] School of Architecture, University of Liverpool, Leverhulme Building, Abercromby Square, Liverpool, L69 7ZN, United Kingdom.

[3] Department of Construction Engineering and Architecture, Faculty of Civil and Environmental Engineering, University Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

Corresponding email: lokman@uthm.edu.my

Abstract

The shift towards a more sustainable architecture for high-rise building is discussed and illustrated through the work of Ken Yeang and other architects. The claimed benefits of such a bioclimatic design approach are examined in the light of the results of previously conducted research projects, dealing with indoor thermal condition of high-rise office buildings. This paper reports on a study to determine if high-rise buildings designed on bioclimatic principles perform better than conventional designed ones, when situated in a tropical climate such as that in Malaysia. The paper describes a number of case studies which compare Malaysian bioclimatic and conventional building using indoor environmental parameter criteria such as air temperature, relative humidity and air velocity. Building energy index for both types of buildings is presented to illustrate the real energy savings in both types of buildings. The major finding of this work is that, the bioclimatic buildings offering a more comfortable indoor environment, increase satisfaction and show an improvement in energy saving.

Keywords: Bioclimatic, High-rise, Sustainable Architecture, Tropical Climate, Comfort.

1. INTRODUCTION

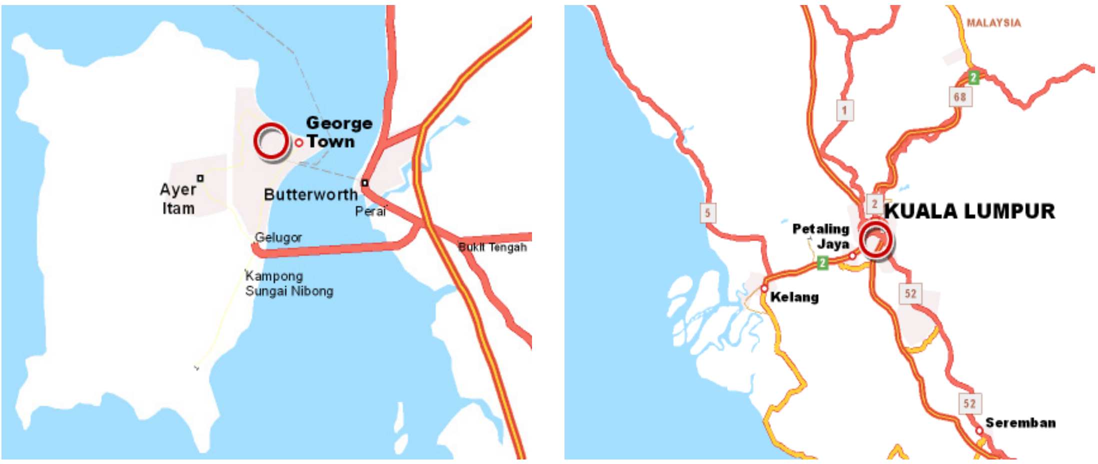
Malaysian architecture has experienced major transformation, as many colonial towns have turned into the new state capitals. Symbols of nationhood were articulated in new and daring form of buildings, houses and structures designed by overseas trained Malaysian architects [1]. Creative and innovative procedure which were applied in the construction industry have changed the dimension of commercial and residential buildings and have also enabled the establishment of high-rise buildings in the capital city of Kuala Lumpur and other major cities such as Penang and Shah Alam. These buildings are metaphorically allied with a drastic expanding economy and an indication of progress, aimed at moving Malaysia at the forefront of the developing countries in the province [2]. The bioclimatic approach design for high-rise buildings was introduced and implemented by a few architects who learnt from their experiences. The Malay vernacular architecture has modified their styles in order to adapt to the new building typologies without disregarding the local climatic and environmental conditions. The approach was later presumed to be the corrective strategies of the early high-rises. However, the rationale for adapting the bioclimatic approach to high-rise design is that it can address many of the problems which conventional high-rise design does not.

2. RESEARCH DESIGN AND METHODOLOGY

This paper presents the comparison study and the interaction between architectural features with the environmental aspects. Several equipments matched most closely to the required tool for this study were used to obtained environmental data. Energy index in a form of electricity consumption data sheet of every single building is determined in this study. Buildings are compared to indicate the energy saving achievement or performance.

3. CASE STUDIES CHARACTERISTICS

The study took place in the northern (Penang) and middle (Kuala Lumpur) region of the peninsular Malaysia where most high rise buildings were located. The location of the case study is shown in figure 1.



Pulau Pinang
(Area: 1,031 km^2)
Population: 1,313,449

Kuala Lumpur
(Area: 243 km^2)
Population: 1,379,310

Figure 1: Location of cases study (Penang and Kuala Lumpur)

The tropical climate of Malaysia can be classified as warm-humid equatorial, having high temperature and humidity throughout the year, obtains intense sunshine, high temperature, strong glare, high radiation levels and rainfall. The air temperature average is consistent between 26°C and 32°C with high relative humidity ranging from 70% to 90%. The annual mean temperature is about 27°C (80°F) with the average monthly temperature ranging from 1 - 3°C (2 - 5.5°F). Average maximum temperatures are about 30°C (86°F) and sometimes may reach 38°C (100°F) on clear days [3, 4]. Winds are generally low with variable speed but sometimes strong when combined with the rain. Rainfall is high over the year with an average between 2500 mm to 3000 mm annually and is more intense with the monsoons [5]. The monthly average daily solar radiation in Malaysia is around 4000 - 5000 Whr/m^2, with the monthly average daily sunshine duration ranging from 4 to 8 hours [6].

There are four high-rise office buildings were involved in this study and were classified into two different types based on the criteria they were designed. Based on the bioclimatic indicators for high rise building [7] and observation during the field work, there were 13 bioclimatic features identified in UMNO building and 16 features in MESINIAGA, whereas only 4 bioclimatic features were found present in LUTH tower and 8 features in TIMA tower. UMNO and MESINIAGA towers are considered to represent bioclimatic design whereas TIMA and LUTH towers are that for conventional. The indicators found in all cases study buildings are shown in Table 1 and the appearance and characteristic of the case study buildings are shown in figure 2-5.

Table 1: Bioclimatic indicators for high rise buildings

INDICATORS \ BUILDING	UMNO	MESINIAGA	TIMA	LUTH
Bioclimatic Strategies				
Plan/Use patterns/ ventilation	√	√		
Recessed sun spaces		√		
Balconies and terraces	√	√		
Vertical landscaping		√		
Site/Building solar sky-court	√	√		
View out from lobby	√	√	√	
Environmental interactive wall	√	√	√	
Transitional spaces		√		
Site building adjustment	√	√	√	
Curtain wall at N & S facades	√	√	√	√
Open to sky ground		√		√
Form and Envelope				
Shading devices	√	√	√	
Wind scoops	√	√	√	
Wind ducts	√	√		
Insulative wall	√	√	√	√
Cores at hot side (single/double core)	√	√	√	
Central core				√
TOTAL	**13**	**16**	**8**	**4**

Figure 2: United Malay National Organisation Building (UMNO Tower)

Figure 3: Mesiniaga Building (MESINIAGA Tower)

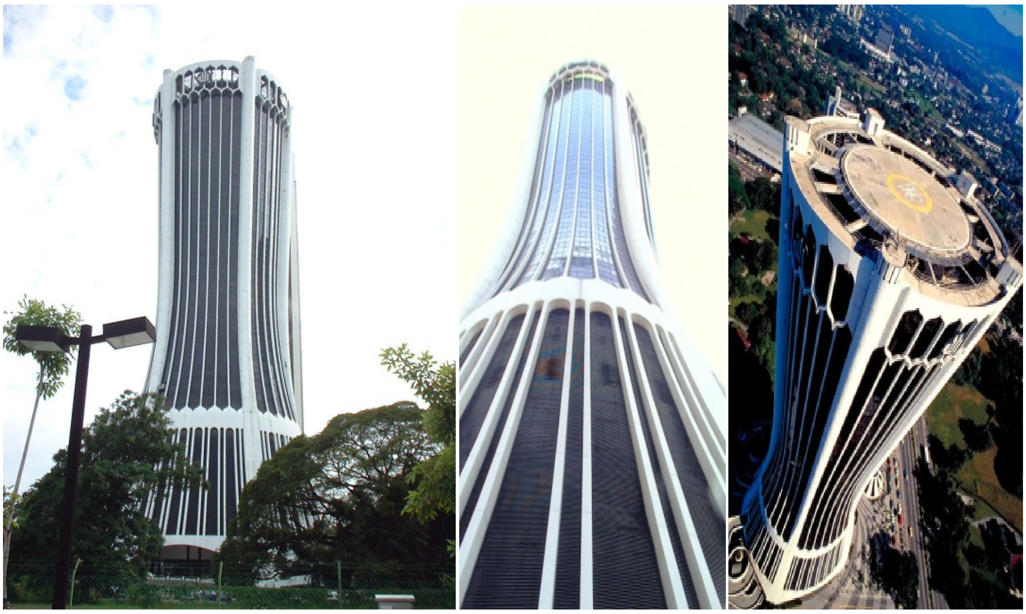
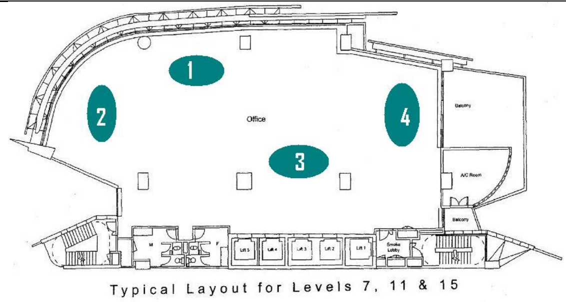


Figure 4: Lembaga Urusan Tabung Haji Building (LUTH Tower)

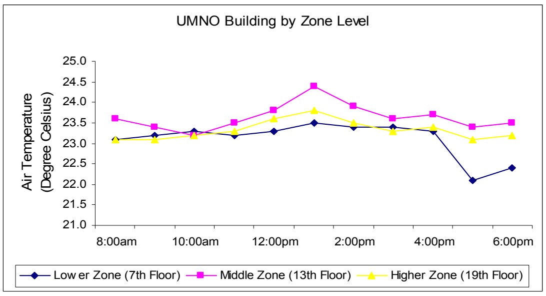
Figure 5: Tun Ismail Mohd Ali Building (TIMA Tower)

4. ENVIRONMENTAL PARAMETERS MEASUREMENT

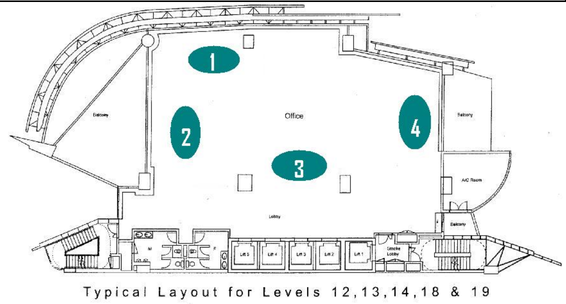
The indoor environment parameters measured in all case study buildings are air temperature, relative humidity and air velocity. Measurements were obtained from several areas inside the buildings in three different classifications of zones which are lower, middle and higher zones. The reading of the measurement in each zone is recorded and plotted into an appropriate graph for technical assessment as shown in figure 6-9.



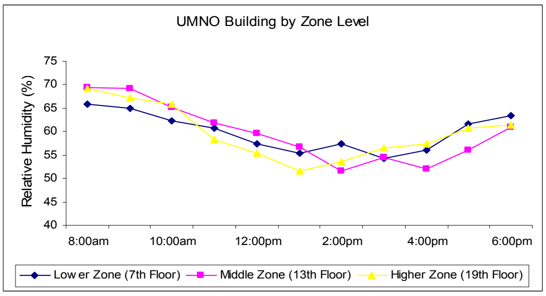
Lower Zone (7th Floor)



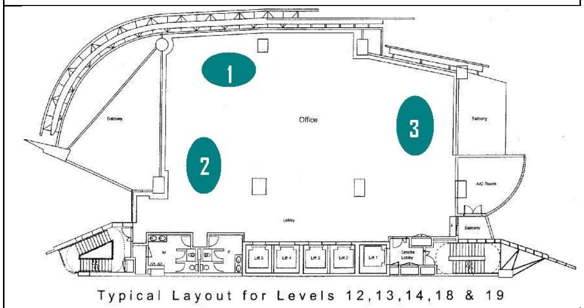
Air temperature reading by zone level



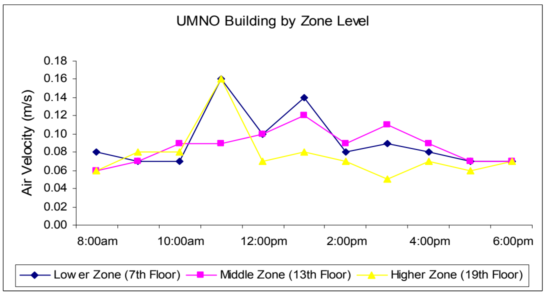
Middle Zone (13th Floor)



Relative humidity reading by zone level

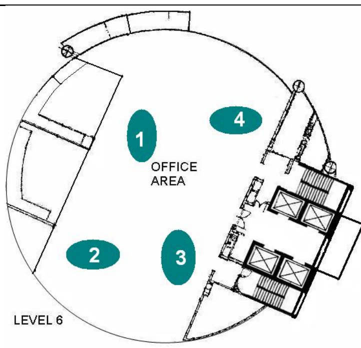


Higher Zone (19th Floor)

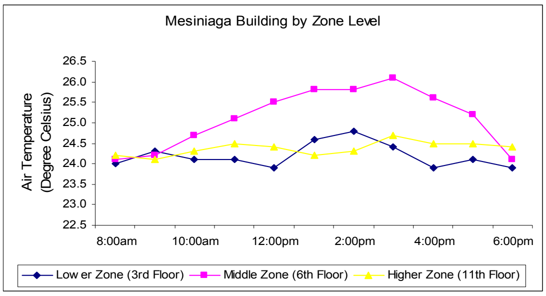


Air velocity reading by zone level

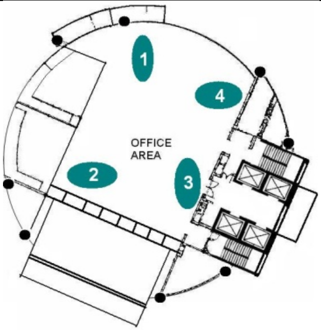
Figure 6: UMNO Tower: Location area of measured parameters



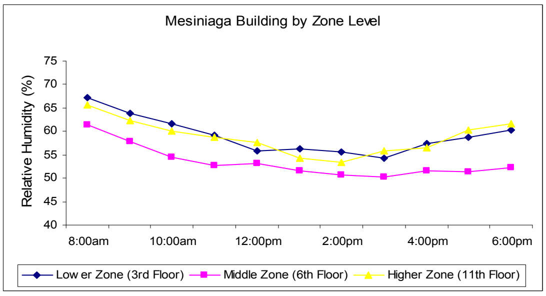
Lower Zone (3rd Floor)



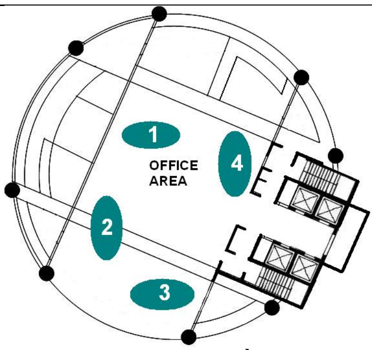
Air temperature reading by zone level



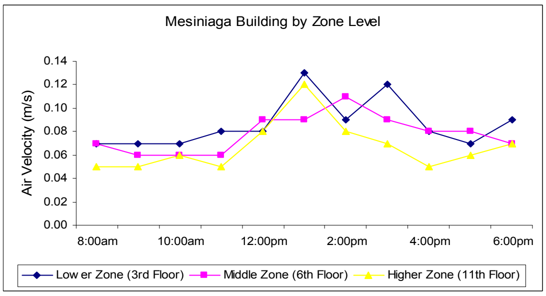
Middle Zone (6th Floor)



Relative humidity reading by zone level



Higher Zone (11th Floor)



Air velocity reading by zone level

Figure 7: MESINIAGA Tower: Location area of measured parameters

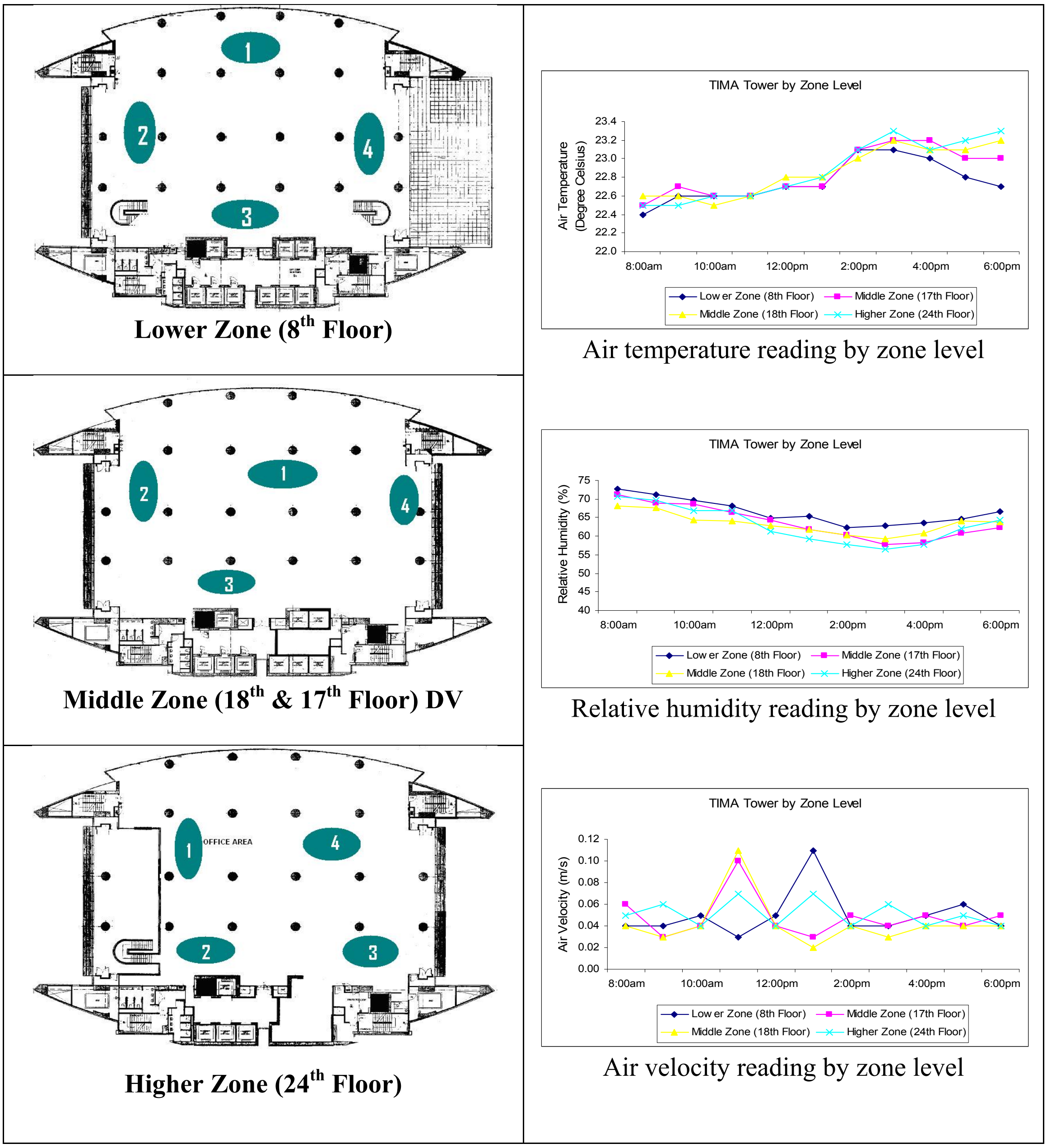
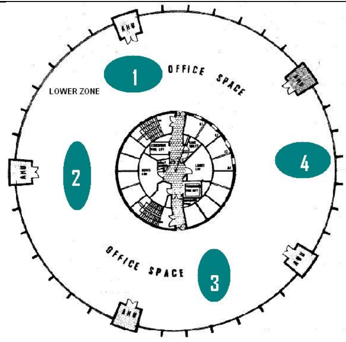
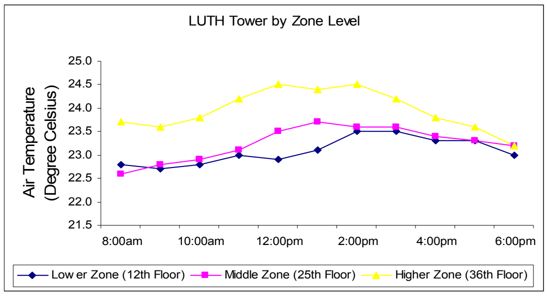


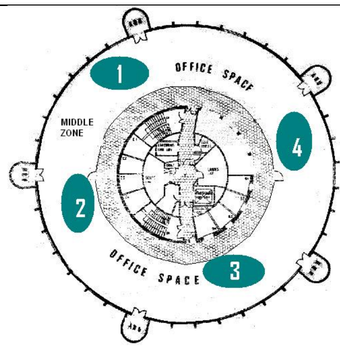
Figure 8: TIMA Tower: Location area of measured parameters



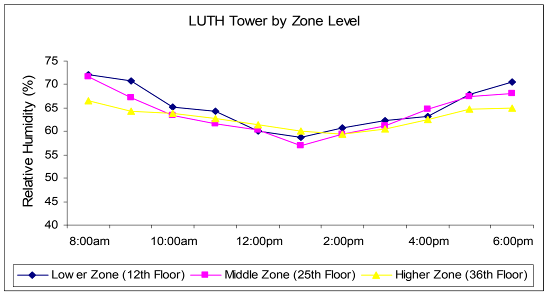
Lower Zone (12th Floor)



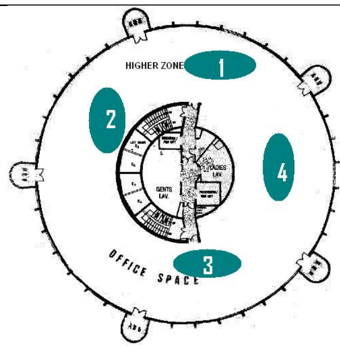
Air temperature reading by zone level



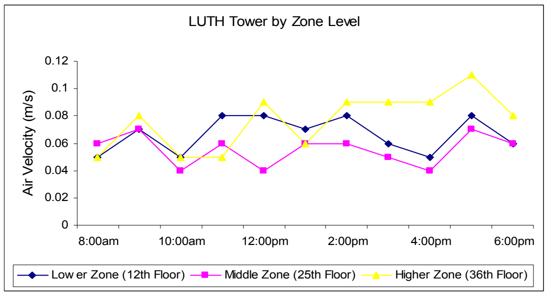
Middle Zone (25th Floor)



Relative humidity reading by zone level



Higher Zone (36th Floor)



Air velocity reading by zone level

Figure 9: LUTH Tower: Location area of measured parameters

4.1 Air Temperature (T_a)

Air temperatures were measured using a Hygro-Thermo-Anemometer and hourly indoor air temperature averages for all buildings are shown in table 2. Among all buildings, TIMA tower has the lowest indoor air temperature on average, whereas MESINIAGA have the highest average (see table 2). The calculated average indoor air temperature for bioclimatic buildings is 24.0°C and the minimum and maximum average is 23.0°C and 25.3°C respectively. The calculated average for conventional buildings is 23.1°C and the minimum and maximum average is 22.5°C and 23.9°C. In comparison between bioclimatic and conventional type, it appears that the conventional type has a lower indoor air temperature than bioclimatic type by 1 to 1.5°C. The comparison of daytime indoor temperature for all buildings can be seen in a graph diagram as shown in figure 10.

Table 2: Measured parameter

Air Temperature (^{o}C) T_a	**UMNO**	**MESINIAGA**	**TIMA**	**LUTH**
Average	23.4	24.6	22.8	23.4
Std Dev	0.40	0.61	0.27	0.52
Min	22.1	23.9	22.4	22.6
Max	24.4	26.1	23.3	24.5
Relative Humidity (%) *RH*	**UMNO**	**MESINIAGA**	**TIMA**	**LUTH**
Average	59.8	57.1	64.2	63.9
Std Dev	5.25	4.44	4.16	3.93
Min	51.5	50.2	56.6	56.9
Max	69.4	67.3	72.8	72.2
Air Velocity (ms^{-1}) V_a	**UMNO**	**MESINIAGA**	**TIMA**	**LUTH**
Average	0.09	0.08	0.05	0.07
Std Dev	0.03	0.02	0.02	0.02
Min	0.05	0.05	0.02	0.04
Max	0.16	0.13	0.11	0.11

4.2 Relative Humidity (RH)

Relative humidity in the offices was measured using the same equipment for air temperature, the Hygro-Thermo-Anemometer. By using the same probe (combined temperature and humidity probe), the relative humidity could be measured within the range of 10% to 95% with a resolution of 0.1% and accuracy of ±3%. TIMA shows the highest average of relative humidity (64.2%) among all buildings whereas MESINIAGA is the lowest (57.1%) (see table 2). The calculated average relative humidity for bioclimatic buildings is 58.5% and the minimum and maximum average is 50.9% and 68.4% respectively. Conventional buildings show an average relative humidity of 64.1% whereas the minimum and maximum is 56.8% and 72.5%. Comparatively both conventional buildings have higher relative humidity than that of bioclimatic buildings (see figure 10).

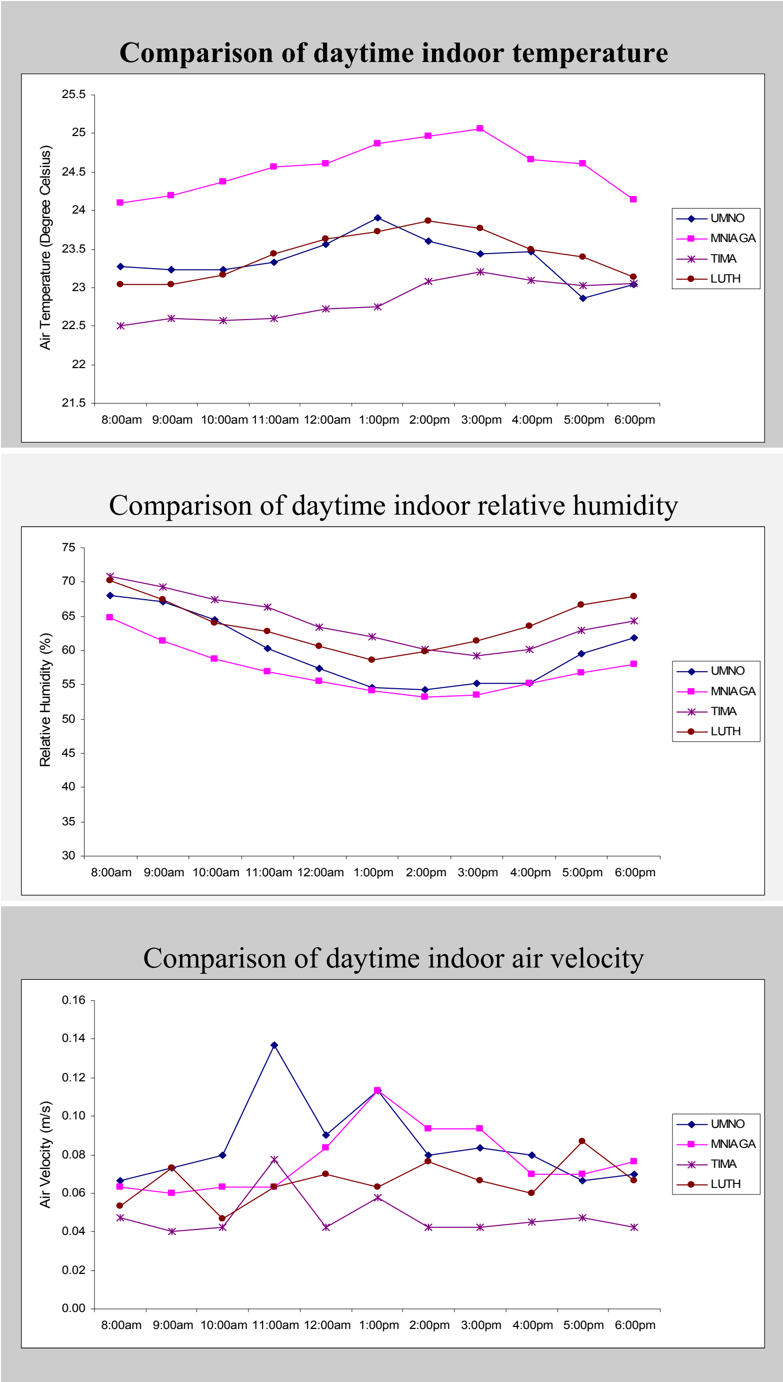


Figure 10: Comparison of indoor environmental parameters

4.3 Air Velocity (V_a)

Using the same equipment the Hygro-Thermo-Anemometer with different type of probe was used to measure air velocity in the offices. The instrument acted as an instant action anemometer with a capability to measure air velocity ranging from 0.4 m/s to 25.0 m/s with a resolution of 1 m/s and accuracy of ±(2% + 1d). Figure 10 shows the hourly air velocity graph diagram for both bioclimatic and conventional building types. The daily air velocity in average bioclimatic building is a bit higher than most conventional building. The bioclimatic buildings (UMNO and MESINIAGA) have an average of 0.09 and 0.08 ms^{-1} respectively whereas the conventional buildings (TIMA and LUTH) have an average of 0.05 and 0.07 ms^{-1} respectively. The minimum and maximum daily indoor air velocity in all bioclimatic buildings is slightly higher than those in conventional buildings as shown in table 2.

Givoni mentioned that the comfort zone in a warm humid country happens when indoor air speed is between 1.5 – 2.0 m/s, relative humidity within 50%, indoor temperature between 20°C and 30°C [8]. Szokolay suggested that air cooling through air movement of 1.0 m/s to 1.5 m/s is the best passive means to achieve comfort in this climate [9]. In CIBSE Guide A1 the comfort zone in the tropics during summer will occurs when the relative humidity is between 45% and 70%, indoor temperature between 23.0°C and 26.0°C [10]. In ASHRAE Standard 55 it is also recommended that the comfort temperature range in temperate climates during summer is between 23.0°C and 26.0°C and the comfort value to be 24.5°C, 50% relative humidity and 0.15m/s mean air speed [11]. In ISO 7730, it is suggested the comfort temperature range in temperate climates during summer is also between 23.0°C and 26.0°C and the comfort value to be 24.5°C, relative humidity between 30% and 70% and 0.4m/s mean air velocity [12].

In the late 80s a study using an energy audit technique in Malaysia found that the comfort temperature in office building ranges from 23.0°C to 27.0°C and, relative humidity between 60% and 70% [13]. Another study in the early 90s using a laboratory method found the comfort range is between 25.0°C to 31.4°C with 50% relative humidity [14]. A field studies approach done in the late 90s found that the comfort temperature in office building ranges from 20.8°C to 28.6°C and, relative humidity between 40% and 80% [15]. In all cases different comfort values for office building in Malaysian were obtained by energy audit technique 25.0°C, laboratory method 28.2°C and the fields study approach 24.7°C.

In this study, for all buildings except for TIMA tower, indoor air temperature average (see table 2) was within the comfort range for non residential buildings (23°C – 26°C) suggested by the Ministry of Energy, Communications and Multimedia [16] and the Malaysian Standards 1525 [17]. These figures are similar to the ASHRAE Standard 55 [11] and ISO 7730 [12]. The measurements in all bioclimatic and conventional buildings show that bioclimatic buildings have temperature slightly higher than that of conventional buildings, ranging average from 23.4°C to 24.6°C for bioclimatic buildings and from 22.8°C to 23.4°C for conventional ones. This significantly shows the relative humidity average for all bioclimatic buildings; 58.5% slightly lower than that of conventional types; 64.1%. The air velocity in bioclimatic buildings on average is shown to be a bit higher than the conventional ones with an average of 0.08 ms^{-1} and 0.06 ms^{-1} respectively.

It has been noted that all conventional buildings are fully air conditioned and concealed from the outside environment except through intake air from the air conditioner systems. Although the bioclimatic buildings in these cases studies are naturally ventilated mostly only at the communal spaces, there is possibility that outside warm air penetrated into the office area through occupants' movement in and out the office area. Although the impact is very small depending on the occurrence of the occupant movement, these will significantly decrease the humidity level and increase the air temperature and the air velocity in the office spaces. Furthermore in most buildings (i.e. MESINIAGA, UMNO and TIMA) there are areas where open able windows segment are available within the glazed façade of the buildings particularly in the office spaces.

Despite the fact that these windows are normally closed most of the time, at certain times these windows were left opened by the occupants. However the average for minimum and maximum air velocity readings for bioclimatic buildings are between 0.05ms^{-1} (min) and 0.16ms^{-1} (max) whereas for conventional buildings they are slightly lower; 0.02ms^{-1} (min) and 0.11ms^{-1} (max) (see table 2).

5. BUILDING ENERGY AUDITS

The electricity consumption is mostly used to provide indoor comfort to the users, related to lighting and air conditioning systems in the building. This part presents the calculated building energy index analysed from the breakdown of electricity bills obtained from the management office. The amount used in the two different types of high rise office buildings were compared to check whether there were real energy savings in the bioclimatic high rise office blocks or not.

The calculated energy consumption for MESINIAGA was found to be the highest among all buildings. TIMA shows the lowest followed by UMNO and LUTH. Table 3 summarizes the calculation method adopted from *CIBSE TM31* [18]. It was quite surprising that MESINIAGA consumed the most energy compared to the other buildings. The total electricity consumption for MESINIAGA is 2,854,889kWh/year and the building energy index is 260kWh/m^2/year. It is more than double amount of the lowest found in this study, (TIMA) which is 102kWh/m^2/year.

Table 3: Energy consumption in all buildings

BUILDING	UMNO	MESINIAGA	LUTH	TIMA
Total Build Up Area (m^2)	7,412.92	10,960.31	28,761.95	28,125.19
Average Yearly (kWh/year)	958,140.00	2,854,889.10	5,496,976.57	2,874,137.14
Average Monthly (kWh/month)	79,845.00	237,907.43	458,081.38	239,511.43
Average Daily (kWh/day)	2,625.04	7,821.61	15,060.21	7,874.35
Usage/m^2/year (kWh/m^2/year)	129.25	260.48	191.12	102.19
Usage/m^2 /month (kWh/m^2/month)	10.77	21.71	15.93	8.52
Usage/m^2 /day (kWh/m^2/day)	0.35	0.71	0.52	0.28

Based on the energy consumption calculated for the cases study buildings, the CO_2 emissions produced can be calculated using Energy Assessment and Reporting Methodology: Office Assessment Method [19]. Table 4 shows the actual CO_2 emissions per square meter produced by those buildings. The higher the amount of energy used in a particular building, the higher the amount of CO_2 emission produced for every meter square of the building area. In this case MESINIAGA is the highest contribution to CO_2 emission.

Table 4: Overall Annual Energy Performance (electricity) and CO_2 emission

Building Energy Performance for Electricity (12 month) Period Based on a Gross Floor Area (m^2)				
BUILDING	**UMNO**	**MESINIAGA**	**LUTH**	**TIMA**
Gross Floor Area (m^2)	7,412.92	10,960.31	28,761.95	28,125.19
[A]Quantity (kWh)	958,140.00	2,854,889.10	5,496,976.57	2,874,137.14
[B] CO_2 ratio (kg CO_2/kWh)	0.43*	0.43*	0.43*	0.43*
[C] CO_2 emission (kg CO_2/year)	412,000.20	1,227,602.31	2,363,699.93	1,235,878.97
[D] Actual CO_2 emission (kg CO_2/m^2/year)	**55.58**	**112.00**	**82.18**	**43.94**

**This value may change year to year due to changes in the mix of electricity generation plant.* Ensure that actual consumption figures do not include estimated bills and ensure they relate to a full exact 12 months period. Multiply column [A] by column [B] to get column [C] then divided by treated total building floor area to get [D]

MESINIAGA was completed with enhancement criteria which include the circular plan form with service core facing the morning sun, external sunshades positioned according to sun-path, transitional spaces with landscaping (called sky courts) on every floor that act as thermal buffers, toilets and fire escape stairs situated on the plan periphery able to function with natural ventilation, admission of daylight through the window glazing.

UMNO which was completed a few years later has all of the Bioclimatic attributes of MESINIAGA with additional bioclimatic features which is the rectilinear plan form with service core facing morning sun and external walls (wind wing walls) and operable windows which act together to draw air through each floor for the purpose of ‘comfort cooling’. Furthermore it offers the occupants a choice of operational modes at their workspace to be naturally ventilated or with air conditioned.
The electricity consumption for MESINIAGA is 260 kWh/m^2/year whereas for UMNO is 129 kWh/m^2/year. This is a very good performance compared to typical new office buildings in Malaysia and the ASEAN region, having an Energy Index of 200 – 300 kWh/m2/year [16]. However, if we refer to the current Malaysian Standard MS 1525 [17]: "*Code of Practice on Energy Efficiency and use of Renewable Energy for Non-residential Buildings*", MESINIAGA is not entitled to be classified as a low energy office building as well as the conventional building, LUTH. Following this code, the low energy office building must have an energy consumption less than 135 kWh/m^2/year. UMNO and TIMA are still well classified as a low energy office building. This shows how the latest bioclimatic high rise office buildings consumed lesser energy compared to the earliest ones and compared to the conventional buildings.

6. CONCLUSION

Although there are differences in terms of those environmental parameters among all buildings and between conventional and bioclimatic buildings types, it was found that the indoor conditions for all buildings are within the acceptable comfort zones determined by many related organisation in many of their standards. The study shows evidence that the indoor thermal and ventilation condition in bioclimatic buildings are better than that of conventional ones as expected. Both bioclimatic buildings are mostly better than conventional buildings. In terms of energy used, bioclimatic buildings are clearly shifting towards a lower energy building and meet the local energy index for offices.

REFERENCES

[1] Ruby, L. and Christ, L., (1998). Arrival of the international style - The Encyclopaedia of Malaysia Architecture, Volume (5): 103. Archipelago Press. Malaysia.
[2] Chen, V.F., (1998). Introduction - The Encyclopaedia of Malaysia Architecture, Volume (5): 6 - 7. Archipelago Press. Malaysia.
[3] Sopian, K., Haris A.H., Rouss D. and Yusof M.A., (2005). Building integrated photovoltaic (bipv) in malaysia – potential, current status, and strategies for long term cost reduction. Universiti Kebangsaan Malaysia.
[4] Ismail, M.R. and Barber, J.M., (2001). A field study to determine inside design conditions for Malaysian air conditioning systems. Architectural Science Review, Volume 44, pp 83 - 99.
[5] Yeang, K., (1986). Land Use, Climate and Architectural Form. In Design for High-Intensity Development. pp 75 - 79.
[6] Sopian, K. and Othman M.Y., (1992). Estimates of monthly average daily global solar radiation in Malaysia. Renewable Energy, Vol 2(3). pp 319 - 325.
[7] Yeang, K., (1997). *The Skyscraper, Bioclimatically Considered: A Design Primer*. Academy Editions, London.
[8] Givoni, B., (1994). Passive and Low Energy Cooling of Building, John Wiley & Son. Inc., New York.
[9] Szokolay, S., (2000). Dilemmas of warm-humid climate house design: Heavy vs. lightweight cooling effect of air movement, Architecture, City & Environment, Proceeding CD PLEA International Conference, Cambridge.
[10] CIBSE, (1978). CIBSE Guide A1: Environmental Criteria for Design. Chartered Institution of Building Services Engineers, London.
[11] ASHRAE, (1992). Standard 55-92: Thermal Environmental Condition for Human Occupancy. American Society of Heating Refrigerating and Air-Conditioning Engineers, Atlanta.
[12] ISO 7730, (1994). Moderate Thermal Environments - Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort. International Standards Organisation, Geneva.
[13] Kannan, K.S., (1997). Development of Energy Conservation Requirements in Malaysian Buildings. ASHRAE Far East Conference on Air Conditioning in Hot Climates, September 3-5, Singapore, 1997. pp 293 - 301.
[14] Abdul Shukor, A., (1995). Human Thermal Comfort in Tropical Climates. PhD Thesis, Bartlett School of Architecture, University College London, UK.
[15] Ismail, M.R., (2000), An Investigation into the Choice of Air-Conditioning Design Conditions for Malaysian Offices and Their Effect on Energy Consumption in Malaysia. PhD Thesis, University of Liverpool, UK.
[16] MECM, (2004). Low Energy Office Building. Ministry of Energy, Communications and Multimedia MECM. Putrajaya, Malaysia.
[17] Malaysian Department of Standards (2001), Malaysian Standards MS 1525.
[18] CIBSE, (2003). CIBSE TM31: Building energy log book. Chartered Institution of Building Services Engineers, London.
[19] CIBSE, (1999). Energy Assessment and Reporting Methodology: Office Assessment Method, CIBSE TM22. The Chartered Institution of Building Services Engineers London, the Department of the Environment, Transport and the Regions, BRE Ltd. ISBN 0-900953-93-4.