Title:	**Tower Buildings in Dubai – Are they Sustainable?**
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Subjects:	Architectural/Design Sustainability/Green/Energy
Keywords:	Climate Sustainability
Publication Date:	2004
Original Publication:	CTBUH 2004 Seoul Conference
Paper Type:	1. Book chapter/Part chapter 2. Journal paper 3. **Conference proceeding** 4. Unpublished conference paper 5. Magazine article 6. Unpublished

Tower Buildings in Dubai – Are they Sustainable?

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Abstract

The active construction of tall buildings in the UAE, as a result of the rapid growth of economy, goes in a fast pace and has not allowed enough time to study and realize the adverse impacts on the environment. This study assesses to what extent new tower buildings in the UAE, with specific emphasis on Dubai, are sustainable in its environment, under the harsh desert climate of the UAE. Several issues are investigated such as energy consumption, thermal performance, lighting design, and the potential use of renewable energy resources. How these issues are affected by the design of building form, envelope, components and systems is the focus of this study. The study depends on analysis of three case study office towers located in the UAE and are well known internationally. It concludes with some recommendations and guidelines aiming to help decision makers and designers in future projects.

Keywords: Sustainable buildings, green architecture, tall buildings, desert climate, Dubai

1. Introduction

Since a decade, architecture in Dubai has been shifting into large scale projects -- or the so called mega projects -- with specific emphasis on tower architecture. The government of Dubai and the private sector has been spending billions of dollars to construct new tower buildings which can be seen in the Dubai's skyline every year. The active construction of these tall buildings, as a result of rapid growth of the city and its economy, goes in a fast pace and has not allowed enough time to study and realize the adverse impacts on the environment. Accordingly the issue of sustainability has been neglected. More importantly, this issue and its threats on ecology and human lives still have not been seen as a priority of the Dubai government. This construction movement emerged as a result of the current economy boom in Dubai which will probably last for a number of years or at the most few decades. Economy booming in the history of many cities in other parts of the world did not last many years as it was thought and probably was limited to one, or maximum two decades. Such a research is conceived as highly significant at this point of the history of Dubai since these buildings are increasing without knowing their impact on the natural and built environment. The purpose of this study is to assess to what extent these new tower buildings are sustainable in its environment, under the harsh desert climate of the UAE.

2. Background

A study by Aboulnaga and Elshishtawy (2001) indicated that contemporary buildings in the UAE used almost six times more energy than traditional buildings. The lack of any energy saving features made the energy consumption of these buildings relatively high compared to other examples in Europe. The issues of high energy consumption and CO2 emission are alarming. Public buildings in the UAE showed less sustainable measures regarding energy-saving features, energy performance, environmental features, and even privacy. The study introduced an environmental assessment tool and guidelines that can be further developed.

Based on a DOE-2 computer simulation study, Lam (2000) has investigated the energy performance of commercial buildings in Hong Kong. The study used a generic office building that was developed based on a survey of large number of buildings. The overall thermal transfer value (OTTV) concept was extended to correlate the OTTV of building envelope designs with other key building design parameters. The most important findings are as follows:

The study showed that the lighting load has a much higher, sensitivity coefficient than the building envelope, indicating greater influences. Lowering the lighting load from the current 20-12.5 W/m2 for an office with an indoor illuminance of 500 lux, the total energy consumption could be reduced to about 15%.

In cooling-dominated commercial buildings in the subtropics, daylight can result in significant energy savings. That is because: (1) less artificial lighting is used, and (2) daylight has a higher luminous efficacy (110 lumens/W in Hong Kong) than most electric lighting systems (60 lumens/W), thus generating less heat per lighting level provided.

For generic office buildings, air-conditioning accounts for 60% of the total building energy consumption. Improving the chiller COP of generic office buildings

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from 3 to 5 can reduce the total building electricity use by 16%.

Alshaibani (2001) investigated the potentiality of daylight to save energy in buildings in the eastern coast of Saudi Arabia. The percentage of occurrence of the vertical illuminance of 10638 lux during a full year was estimated based on daylight requirement of 500 lux inside a room prototype with certain size and glazing properties (width: 4 m, depth: 5 m, height: 2.8 m, reflectance: 0.47, transmittance: 0.7). The study showed that the vertical illuminance of 10638 lux was available at the four orientations for more than 75% of the working year; and hence, this indicated a potentiality of 75% savings in artificial lighting consumption.

Heat island effect has a great impact in exacerbating cooling energy requirements in warm to hot climates in summer. For US cities with population larger than 100000 the peak electricity load increases 2.5 to 3.5 percent for every °C increase in temperature (Akbari et al, 1992). Taking into account that urban temperatures during summer afternoons in US have increased by 1 to 2 °C during the last forty years, it can be assumed that 3 to 8 percent of the current urban electricity demand is used to compensate for the heat island effect alone. For USA the electricity costs for summer heat island alone could be over $1 million per hour, or over $1 billion per year, (Akbari et al, 1992). The possible increase of the peak cooling electricity load due to heat island effect could range from 0.8 to 5 percent for each °C rise in temperature, based on computer calculations done for the whole country. Sanatmouris et at (2001) assessed the impact of the urban climate on the energy consumption of buildings based on climatic measurements from almost 30 urban and suburban stations as well as specific measurements performed in 10 urban canyons in Athens, Greece. It is found that the cooling of urban buildings may be doubled and the peak electricity load for cooling purposes may be tripled while the minimum COP value for air conditioning may be decreased up to 25% because of the higher ambient temperatures caused by urban heat island. Their calculations showed that air flow rates inside urban canyons may be reduced up to 10 times compared to those when undistributed ambient meteorological data were used. That is serious reduction of the natural ventilation potential inside urban canyons.

It is necessary to offset the effects of increased energy consumption for cooling in buildings. Some significant solutions were addressed by Sanatmouris[1]. They are as follows:

Improvement of ambient microclimate in the urban environment – this involves the use of more appropriate materials, increased use of green areas, use of cool sinks for heat dissipation, appropriate layout of urban canopies.

Adaptation of urban buildings to specific environmental conditions – efficiently incorporate energy saving measures and counterbalance major changes of the urban environment including radiative, thermal, moisture and aerodynamic effects. This incorporates appropriate sizing and placing of the building openings, enhance air flow and natural ventilation, improve daylight availability, and use of passive cooling techniques to decrease cooling energy consumption and improve thermal comfort.

The use of more efficient advanced air conditioning systems for individual buildings and optimize them to operate in urban conditions. This involve systems with optimized COP curves for the specific temperature and humidity conditions, systems using advanced inverters, intelligent control, etc.

The use of centralized or semi centralized production, management and distribution cooling net-works, (district cooling), together with the use of demand side management actions like local or remote cycling.

In particular, application of passive cooling techniques in buildings has been proved to be extremely effective and can contribute highly to decrease the cooling load of buildings, (Santamouris and Assimakopoulos, 1997). These techniques can be classified as follows:

- *Preventive techniques* - Protection from solar and heat gains should involve the following measures: landscaping, and the use of outdoor and semi outdoor spaces, building form, layout and external finishing, solar control and shading of building surfaces, thermal insulation, control of internal gains.
- *Modulation of heat gains techniques* - this has to do with the capacity for heat storage in the building structure. This delay strategy depends on decreasing of peaks in cooling load and modulation of internal temperature with heat discharge at a later time.
- *Heat dissipation techniques* - these techniques depends on the potential for disposal of excess heat by natural means. This requires two main conditions: a) The availability of an appropriate environmental heat sink and b) The appropriate thermal coupling and sufficient temperature differences for the transfers of heat from indoor spaces to sink. The main processes and heat sinks required can include radiative cooling using the sky, evaporative cooling using air and water, convective cooling, using air and ground soil.

District cooling provides opportunities to significantly reduce electrical consumption, and thus pollutant emissions[2]. Buildings with on-site room or centralized air conditioner must have equipment sized to meet the peak cooling demand. The peak power demands of buildings are generally not coincident. When a district cooling system is implemented, it uses a central production plant with smoother load distribution. The global peak power demand is then reduced, and thus the plant can be sized considerably smaller. The district cooling plant may take advantage of the usually rejected heat from a gas turbine to operate an absorption cooling machine; the efficiency may reach 80% instead of 40% for a power plant alone.

3. Methodology

The methodology depends on sustainable design guidelines of tall buildings, derived from Yeang (1999), which were then developed as basis for analysis and comparison of three well-known case study buildings located in Dubai and Abu Dhabi. Collection of data depended on energy audit and building design survey using a structured questionnaire; in addition to other research techniques that included literature surveys, internet surveys, building drawings and specifications surveys, interviews, and digital photography. Table 1 draws a comparison among the case studies and provides a summary of the most important information.

Table 1. Technical and design information of the case studies as summarized from the energy audit and building design survey questionnaires.

Name of the Building	**Dubai World Trade Center (DWTC)**	**Emirates Towers Office Building (ETOB)**	**National Bank of Abu Dhabi Headquarter (NBAD)**
BASIC INFORMATION			
Client/Owner	Dubai Government	HH Sheikh Mohammed bin Rashid Al Makhtoum	NBAD
Location	Sheikh Zayed Road, Dubai	Sheikh Zayed Road, Dubai	Khalifa Street, Abu Dhabi
Architect	John R. Harns	Hazel Wong	Carlos Ott
Other Consultants		NORR, Hyder, DSSR	APG
Date Completed	1979	Opened April 2000	Feb. 2003
Gross Area	46,567 m2	64,000 m2	37000 m2
Construction Cost	N/A	N/A	200,000,000 AED
ENERGY PERFORMANCE			
Total Energy Consumption	278 KwH/m2/year	560 KwH/m2/year	N/A
Artificial lighting	40%	N/A	N/A
Refrigeration cooling	1600 tons	N/A	1500 tons
Mechanical ventilation	20%	N/A	N/A
Total estimated CO2 output	700 ppm	Not known	Not known
ENERGY FEATURES			
Natural vent. (% of floor area)	20%	Nil	Nil
Thermal Transmission of Building Envelope	Not known	Not known	Above standard
Night-time Ventilation Provision	Forced, through BMS ventilation is provided as per the enthalpy reading	Forced	Forced
Utilization of Building Mass for Thermal Storage	No	No	Yes
Solar Control Systems	External eggcrate shading devices	Only internal blinds	Only internal blinds
Glazing Type	Double-layered plain glass	Double-layered, non-tinted, 32 mm sealed unit, 8 mm clear heat strengthened outer light and 8 mm clear heat strengthened inner light with Low E coating, separated by a 16 mm dehydrated air space double sealed	Double-layered, SS08 reflective stainless steel color, 8+16+6 mm
Building designed to maximize use of daylight	Yes	No	No
Net floor area %, needing artificial lighting	60%	100%	100%
Energy-saving controls for artificial lighting	Building Management System	Computer based centralized lighting control system	Lighting control system, access control system
Use of energy efficient lighting fixtures	Reflective Type diffusers	Modular and compact fluorescent luminaries, each light fixture is attached to a lighting control module which supplies power and enables independent or group dimming and on/off switching	Task oriented fluorescent fixtures with electronic transformer starters saving energy consump. up to 20% & expand tube life up to 30%

It is apparent that tall buildings are more exposed than other types of buildings to the full impact of external temperatures, wind, and solar radiation. Also, tall buildings have a great effect on heat islands generated in urban environments. Designing the appropriate building in terms of built form configuration, form orientation, floor plates, buffer spaces, and construction components/materials can have significant effects on energy conservation and human comfort. Building operational systems are categorized by their functions and their relation and impact on natural resources such as energy and water. According to Yeang (1999), these systems can be categorized to: Passive-Mode Systems, Mixed-Mode Systems, Full-Mode Systems, Water Conservation Strategy, Wastewater and Sewage Recycling Systems, Productive Mode Systems. To create green or environmentally sustainable skyscrapers, Yeang (1999) recommended to maximizing reliance on passive-mode systems while minimizing reliance of full-mode (or active systems). This could be achieved through appropriate design of the built-form configuration, site layout, façade design, solar-control devices, passive daylight devices, envelope materials, vertical landscaping, and passive cooling.

Built-form configuration - the designer should ensure that the long axis of the built form is oriented east-west so that the long side of the building faces north and south. This allows to design the majority of the windows into the north and south walls and accordingly to reduce solar heat gain. As a general rule of thumb, the optimum aspect ratio of the built form should be as 1:2 to 1:3 for climatic zones nearer to the equatorial zone and lesser at the higher latitudes (Cole, 1995; Yeang, 1999).

The arrangement of the building mass should be considered as a factor in bioclimatic design as its position can help to promote or reduce heat gain. In arid and tropical regions, the service cores of the building should be located on the east and west sides of the building, so as to help shade its form from the low angles of the sun during the major part of the day. Studies show that double-core configuration, with window openings running north and south and cores on the east and west, can achieve significant savings in air-conditioning. The advantage of using this placement is to reduce solar heat gain into the internal user spaces and provides a thermal buffer zone to the hot sides, while at the same time maximizing heat loss away from user spaces. There are several benefits in using the peripheral service core: no fire-protection pressurization duct is needed, resulting in lower initial and operating costs, provision of natural ventilation to the lift lobbies and thus further energy savings, solar and wind buffer effects, provision of natural sunlight to the lift and stair lobbies, a safer building in event of total power failure or fire, better awareness of the place by providing a view out for users.

Floor-Plate Design - the strategy is about the relationship of the building's floor plate shape, its position on the site, and its orientation to the sun's path and wind direction. In hot arid and tropical climates, the optimum shape is a rectangle that minimizes the length of east and west sides while maximizes that of north and south sides, to reduce solar insolation on wider sides. The internal spaces arrangement should be planned to reduce solar gain into high occupancy spaces while service spaces can be used as solar buffers.

Façade Design **-** A well designed building envelope will yield significant energy savings. Its permeability to light, heat, and air and its visual transparency must be controlled with flexibility of modification, so that the building can react to changing local climatic conditions. The ideal envelope is the one that is environmentally responsive filter. The green approach does not recommend using hermetically sealed skins. The green façade has to be multi-functional: reduces solar heat gain to the internal space through external shading, maximizes the use of daylighting, provides fresh air ventilation, serves as acoustic barrier, and contributes to the building's esthetics. Double skin façades can provide several benefits: solar control, noise reduction, high-wind reduction, natural ventilation**.**

Shading Devices **-** regardless of the latitude, some form of solar shading is needed on east, west, and south sides of the building during the overheated period. Solar heat gain through windows can be reduced by sunshades, balconies, deep recesses, or sky-courts. Shading is also needed to reduce glare and direct daylight into deeper reaches of the floor-plate. Fixed shading devices are effective and not costly; yet it can block the sun during times when it is needed as a result of the time shift between the solar year and thermal year. Movable devices can overcome this problem by its flexibility and control to suit outside conditions. Movable louvers can provide additional protection against heat loss in the winter. Depending upon the season and time of the day, the angle control of the louvers achieves optimal daylight incidence in combination with minimal heat gain. Intelligent façades operate with automated angle control, regulated by incident radiation and outside air temperature.

Glazing Type - clear glass is often preferred as it gives a more natural light into the inside. Tinted glass cannot be a substitute for sun shading. Tinted glass reduces thermal transmission to 20% which is still ineffective in hot climates. It has two negative effects: it conducts heat to inside space after it absorbs it and it reduces daylight significantly. Solar-reflective glass can be used to reduce solar penetration without affecting the view. However, it reduces both short-wave (heat) and long-wave (light) transmission, which results in reducing useful winter heat gain and natural light. It can be used though in climates where heat gain is not desired. Low emissivity glass reduces direct heat gain by transmitting a greater proportion of light than heat. It has the appearance of clear glass and is useful in situations where daylight is desired while solar heat gain should be minimized. It allows the use of larger glazing area for admitting daylight, without necessarily incurring an energy penalty. Other new intelligent glazing systems are currently being researched and some are available today such as photo-chromatics, phase-change materials, holographic and electrically responsive glass. The green approach tends to encourage the use of clear or low emissivity glass.

Passive daylight devices - the objective is to enhance the quality of indoor spaces and cut energy consumption through optimizing the use of daylighting and minimizing the need for artificial lighting. Studies have shown that access to daylight and views provide a feeling of well being. Adequate daylight can easily be introduced to depth of inside spaces up to 4.6 meters (15 feet) with conventional height window. Other experimental advanced daylight systems can passively redirect sunlight to larger depths (4.6-9.1 m, 15-30 feet) using special technologies such as HOE (i.e., holographic optical elements), articulated light shelves, and light pipes. The advantages of these systems are: (1) to increase the daylight illuminance levels at deeper spaces with minimum solar heat gain, and (2) to improve the uniformity of the daylight luminance distribution across the room under variable solar conditions throughout the year. Narrowing the width of floor plate to approximately 14 m (i.e., external wall to wall width) can help to reduce artificial lighting and optimize natural lighting. A room with a height-to-depth ratio of 1:2 with 20% glazing of its external wall area allows good light penetration (i.e., 1.5-2 daylight factors) and can be described as cheerfully daylit. In achieving an acceptable comfort level of daylight, one of the discomforts to be recognized and resolved is the problem of glare. Treatment of this problem requires a lighting strategy and has an implication on energy performance.

Artificial lighting accounts for 10% of the energy used in typical large buildings. Artificial lighting loads can be reduced not only by optimizing building configuration to admit natural light, but also by using more efficient low energy lamps, better electronic ballasts, and high quality fittings. Replacing 75-watt incandescent lamp with an 18-watt compact fluorescent lamp will avoid emitting the equivalent of 4300 kg of carbon dioxide and about 10 kg of sulphur dioxide from a typical generating plant in the USA (Yeang 1999; MacKenzie, 1997; Zeiher, 1996). Lighting switching systems can contribute in achieving significant energy savings. This can be coupled with the building management system (BMS), or by using local controls and ambient light sensors to adjust artificial lighting based on the amount of natural light entering the building. An office with simple daylight strategies (such as sidelights and light shelf) and fluorescent lighting system can achieve 60% total reduction of lighting energy and 51% annual electric energy savings Guzowski et al., 1994).

4. Case Studies Analysis

Dubai World Trade Center Tower (DWTC)

The Dubai World Trade Centre Tower (Fig.1) was inaugurated in 1979 and since then has become a prestigious building on Dubai's skyline[3]. The Tower stands 184 meters high and is one of the tallest buildings in the region. It comprises 39 floors, 28 of them are let commercially with a total net lettable space of approximately 283,000 square feet.

Fig.1. Dubai World Trade Centre Tower.

Built-form Configuration - **the** DWTC tower has a square form with two axes that run northwest-southeast and northeast-southwest. These chosen axes and the building position created façades with the orientations: northeast, southeast, southwest, northwest. Having a symmetrical form in two axes contradicts with climate influence and requirements that differ greatly from one orientation to another. The DWTC tower has a square floor-plate shape with 32m length and small angled corners at 45° (i.e., 2m of each side is cut out by a 45° line). Its aspect ratio, which is 1:1, is not appropriate for a hot humid climate such as Dubai because it gives equal importance to all façades regardless of the evident climatic discrepancies between their orientations. The DWTC tower is served by double internal cores that are located in the center and includes all the service areas. This design configuration is not preferable in a hot humid climate such as Dubai because the cores, by being inside, are not used as solar buffers to protect the tower from the low angle sun coming from east and west. This leads to increase in thermal discomfort and more operation of mechanical systems to cool the building. In addition, this core configuration does not provide other benefits that could have been achieved by the peripheral cores, as mentioned above.

Floor Plate Design **-** All office spaces are arranged along the external walls of the tower with room depth of 4m on the northeast and northwest orientations and 6m on southeast and southwest orientations. There is a 2m width corridor on all four sides of the building that are located between the offices and the central cores. This arrangement gives all offices an outside exposure to natural light and air; yet without equal opportunities. That is because Dubai climate puts more liabilities (and fewer assets) on certain orientation (such as west, southwest, southeast, and east) which results in greater thermal discomfort and energy consumption. The service areas are not used to buffer the offices from the sun and outside hot air.

Façade Design - All façades of the DWTC tower are covered by eggcrate shading devices which is definitely considered as an advantage in the hot climate of Dubai. The size of each unit of the eggcrate is 2m width by 2m height by 1.5m depth, with a deep recess (i.e., distance from window glass) of 1.5m. This provides almost full shading of the window area during the overheated period (calculated as March 15 to October 15). There is a wide air space between the windows and the shading devices, an advantage that permits the circulation of air and prevents heat trap. The windows have double layered clear glass. On the top of the service cores (i.e., at level 36 or 148m), there exists a complete floor that house the main mechanical plant. In addition, the building is protected from the summer high altitude sun by other four levels of top floors; some of which house other mechanical systems in addition to a covered roof at level 35 (140m) and an open observatory area at level 37 (145m).

Natural and Artificial Lighting Systems - During the day, 40% of the offices lighting is provided by natural lighting through the windows (i.e., sidelight systems without light shelves), which cover 77% of the room area. The room height-to-depth ratio is 1:2 with window glazing that is 20% of the external wall area. This is considered optimum for daylight design. The artificial lighting energy consumption is about 40% of the total energy consumption (5183225.6 kW/h.m2.Year). Incandescent lights with reflective diffusers are used to provide artificial lighting to the offices. The artificial lighting is coupled with the Building Management System (BMS) to provide energy saving control.

HVAC systems - All AHU's are fitted with LAH and LEF in the tower with automatic control by BMS to control the fresh air, return air, and exhaust damper. Based on the outside air temperature, these dampers are controlled. In case of fire, the fresh air and exhaust air damper open the return damper while the return air closes; by which CO-2 level in all office area is controlled. The system used for cooling is an indirect cooling system. The cooled media is circulated into different AHU's, in different floor levels. During peak summer, two 800-tons centrifugal chillers are operated, to maintain good 72F comfort temperature. During the operation, 25% of fresh air is at 5-60% RH. Heat recovery is carried out in two ways: thermal wheel and reheat system. The reheat system uses a plated heat exchanger from the condenser water return to the cooling tower via a bypass valve, water at 85F by an LTH pump and feed to the expansion tank located in level 4 platform. The air-conditioned area in the office layout is controlled by VAV in relation with changing heat gains from the occupants and the sun thus saving on operational costs. The air terminals are installed on a modular basis giving maximum flexibility. All the AHU are operated by VFD, thermal wheel to reduce the overall running cost of the refrigeration plant.

Emirates Towers Office Building (ETOB)

The Emirates Towers complex, located in Dubai, comprises two equilateral triangles containing an office tower and 400 bedroom hotel tower, joined by a central podium containing a selection of shops and restaurants, with covered parking for up to 1,800 cars (Fig.2). The office tower, at 350 meters high, is the tallest building in the Middle East and Europe; while at 305 meters, the hotel tower is the third tallest hotel in the world. The ETOB average floor has a net usable area of 810m^2 with 2.85 meters floor-to-ceiling height, and is served by 17 elevators. It has 47 floors of lettable space based on a triangular layout comprising[4]: lobby area and the drum floors (levels 2-8, with 6633-7014 Sq.ft.), the low rise floors (levels 10-20, with 9611 Sq.ft.), the mid rise floors (levels 22-32, with 9611 Sq.ft.), the high rise floors (levels 34-44, with 9611 Sq.ft.), the peak floors (levels 46-51, with 8955 Sq.ft.), the mezzanine (level 52, with 806 Sq.ft.), and other floors designed as transfer floors or for mechanical systems. The total energy consumption of the tower is 560 KwH/m^2/year.

Fig. 2. Emirates Towers – office building (Left); Hotel (Right).

Built-form Configuration **-** the ETOB building has an equilateral triangle floor-plate, with 50.5 m length of side, that is rotated about 50° to the west direction. The main axis of position runs northwest-southeast, which in turn created façades with orientations: north, west, and southeast for the ETOB building. This configuration, as evident by its façade size and treatment, does not respond to differences in climatic effects posed by the different orientations. The aspect ratio of the chosen form is 1:1.15; this aspect ratio is not appropriate for a hot humid climate such as Dubai because it does not take into consideration the impact of climate with regard to different orientations. The typical floor in the ETOB building is served by three cores; a main core located in the center which includes 16 elevators and bathrooms, in addition to two peripheral cores located in two corners of the triangle which include emergency stairs, service elevator, and electrical rooms. The two peripheral cores can function as solar buffers to protect the tower from the low angle sun coming from east and west. This configuration can help to increase thermal comfort and eventually requires less operation of mechanical systems to cool the building, in addition, to other benefits, as mentioned above.

Floor Plate Design **-** All office spaces are arranged in an open floor plan mainly along the external walls of the tower, giving minimum space depth of 8m on the triangle sides, while three times this size on the corners. This arrangement gives all offices an outside exposure to natural light with no consideration of climatic impact differences among orientations.

Façade Design – the building façades are clad by curtain walls with double glazing (i.e., non-tinted, 32 mm sealed unit, 8 mm clear heat strengthened outer light and 8 mm clear heat strengthened inner light with Low E coating, separated by a 16 mm dehydrated air space double sealed). The area of windows in the office building covers about 70% of the façade wall area per floor. The hotel building involves a total exterior building envelope of 50,000 m2 split into approximately

30,000 m2 of aluminum composite cladding and 20,000 m2 of unitized curtain walling[5]. External shading devices are not part of the façade design in both towers, and accordingly the building relies on internal draperies only to provide solar shading. The building is capped by a triangular pyramid with a slope of 1:1 that includes several floors in its inner space used for mechanical systems. This top space helps to create a buffer zone that reduces the solar load generated by the high altitude sun in the Dubai summer. The tower does not include any outdoor spaces designed for human use or plantation such as sky courts or other similar elements.

Natural and Artificial Lighting Systems – the building is not designed to maximize utilization of daylighting; yet, during the day, most of the offices have access to natural lighting through the windows (i.e., sidelight systems without light shelves). The room height-to-depth ratio is 1:2.7 with window glazing that is 30% of the external wall area. The office tower has general and decorative lighting using modular and compact fluorescent luminaries. The general illumination is designed to meet European guidelines for areas where VDU terminals are used. The illumination level for the office area is designed for 500LUX and the low brightness louvers meet the requirement of CIBSE LG3 category 2 criteria[6]. A computer based centralized lighting control system is provided to give the tenant a high level of flexibility for sub division and to provide benefits in terms of reduced fit out work. Each modular light fitting can be individually addressed to suit the tenant's requirements without alteration to base wiring. If required, facilities are also available to allow the tenant to fit movement detectors, manual and infrared switches to suit individual needs. The high frequency control gear allows tenants to dim the fluorescent lighting if required. Emergency lighting is provided on each floor and to all escape routes[7]. Each tower is equipped with a workstation running Delmatic ZMC lighting control software[8]. This object-oriented tool uses the building's CAD drawings and displays all lights and lighting control devices in the entire site. Furthermore, the ZMC software allows lights to be configured in predefined scenes to meet operational requirements. In the office tower each light fixture is attached to a Delmatic lighting control module which supplies power and enables independent or group dimming and on/off switching. Since the module is a node on the LonWorks network, each luminaire is addressed and can be controlled from the two ZMC workstations or a physical switch to which it has been bound. All physical switches and lighting control devices, including floor control switches, are connected to the lighting control modules.

HVAC systems - Central supply and extract systems are provided for toilet and pantry facilities in Cores A and C. Additional generous exhaust can be provided based on tenant's specific requirements[9]. The building uses forced night ventilation system. Each floor is air conditioned using a variable air volume (VAV) packaged compartment unit serving VAV terminal boxes located in ceiling voids to provide a year round designed conditioned space of 22-24°C. The terminal boxes provide the conditioned air via perimeter diffusers and air handling light fixtures. The ceiling space is utilized as the return air plenum for office areas. Ceiling mounted thermostats have sufficient wiring provided to extend the thermostat position to partitions, if provided by incoming tenants.

National Bank of Abu Dhabi (NBAD Tower)

The NBAD, located in Abu Dhabi, is a double tower structure in pyramidal cross section with inversely reflected triangular peaks (Fig.3.) Its gray colored glass clad gives a touch of formality to its prestigious offices and banking center. The pyramidal form is repeated at ground level with one vertex acting as a support point giving way to a grandiose entrance. Inside this space, there is a four storey atrium that is naturally lit which in turn allows for exceptional views both to and from the exterior[10].

Fig. 3. National Bank of Abu Dhabi.

Built-form Configuration - The NBAD tower has a rectangular form with a 39 m length, 33 m width, and a main axis oriented toward north-west. This position gave the form's longer façades northwest and southeast directions, while it gave its shorter façades northeast and southwest directions. Being positioned, with its two curtain wall façades facing northeast and northwest, while the solid service core façades facing southeast and southwest, is a proper design decision; at least for the chosen form and its relation to the urban context. The rectangle form is usually preferable in hot climates, if its floor plan aspect ratio is in the range of 1:2-1:3 and its shorter sides are oriented to east and west. The justification is to reduce the impact of the low altitude sun coming from east and west directions. The floor plan of the NBAD tower, which has an aspect ratio of 1:1.18 (i.e., almost like a square), does not make it an optimum solution for reducing the solar load impact. The NBAD tower is served by an L-shaped service core that is located in the south corner and includes three stairs, eight elevators, bathrooms, pantry, and other rooms for mechanical and electrical equipment. Being a peripheral core makes it preferable. It works as a thermal buffer zone to mitigate the excessive solar heat load coming from the southwest and southeast sides of the building as a result of the low altitude sun. This improves occupants' thermal discomfort and eventually leads to reduce operation of mechanical systems to cool the building, as mentioned above.

Floor Plate Design - the floor plate is a rectangle that is divided diagonally into two equal triangles. One of which faces north with its 90°-corner and includes the main office area; while the other is transformed into an L-shape to form the core area with an intermediate space merged with the main office space. Most of the main office area is located in the north triangle and along its external glazed curtain wall, i.e., on the northeast and northwest. This helps to provide natural lighting for most of the office area. The service core, in contrast, is located in the south triangle; which is an optimum orientation for a core to work as a solar buffer.

Façade Design - the northeast and northwest sides of the building façades are constructed with curtain wall system that includes double glazing windows. The southeast and southwest façades are constructed with dark color marble cladding covering the concrete wall of the service core. On the top of the building, there exist two triangular forms (pyramids) that are equal in floor area and also volume. The first is located on almost half of the floor plan on the north side above the main office area, while the second is located in a higher level (6 floors difference in level) on the south side above the service core area. The first pyramid includes a VIP club designed in an atrium space with mezzanine floors and oriented to the nice view of the Gulf. The second pyramid is designed mainly to include the mechanical plant. Between these two forms, there is a nice shaded skywalk that is designed as a roof garden. These two pyramids in addition to the roof garden create a wide area of shading that protects the tower from the summer high altitude sun.

Natural and Artificial Lighting Systems - during the day, most of the offices area has access to natural lighting through the windows (i.e., sidelight systems without light shelves), which cover 66% of the room area. The room height-to-depth ratio reaches to more than 1:5 with window glazing that is 30% of the external wall area. With this proportion, natural lighting alone is not sufficient to daylit the offices located in the center of the floor plan. The offices are designed as workstations and provided with task-oriented lighting fixtures with electronic transformer starters. This lighting design can save energy consumption up to 20% and expand tube life up to 30%. During off-time, lighting is controlled automatically by Access Control System, in addition to another Lighting Control System that automatically controls lighting in open office areas.

HVAC systems - the building has several types of ventilation systems that are designed to suit different functions and spaces. In the basement, there are three systems for garage supply and exhaust system. The staircases have three Pressurization Systems. Also, in every floor, there are four Smoke Exhaust Systems and four Toilet Exhaust Systems. The design depends on several chillers: 3 water cooled centrifugal chillers in addition to 2 screw water cooled chillers. Fresh air is supplied to floor AHU/FCU by 3 FAHU's.

5. Conclusion

The issue of high consumption of energy in office tower buildings in the UAE and its adverse impact on the environment is alarming and must be considered by decision makers in any future planning. This requires improvement of ambient microclimate in the urban environment, adaptation of urban buildings to passive mode systems for cooling and natural lighting, using more efficient advanced air conditioning systems, and using centralized or semi centralized production, management and distribution cooling net-works. The methodology depends on green design guidelines as basis for analysis and comparison. Based on analysis of three case study office towers located in Dubai and Abu Dhabi, the following can be concluded:

The optimum built-form configuration should be a rectangle within an aspect ratio of 1:2-1:3, with long sides oriented to north-south. It seems that none of the towers under study were found to have this optimum configuration.

Two of the towers have appropriate service-core configuration in which the service core helps as a thermal buffer zone and provides other benefits as a peripheral type; The NBAD seems to have the best service-core configuration regarding these design considerations then comes the ETOB.

Only the DWTC has an appropriate façade design regarding sun shading and permeability to natural air. Both the ETOB and the NBAD have hermetically sealed skin, which is not recommended as a green façade approach. The NBAD is the only case study with a sky-court or roof garden, a highly recommended design technique to reduce solar heat gain and provide pleasant outdoor space. Although they are provided with double glazing windows, none of the case studies use double skin façade, a recommended design approach for .solar control, noise reduction, and natural ventilation. Only the NBAD utilizes its building mass for thermal storage.

Only the DWTC is designed to maximize use of daylight. The room height-to-depth ratio is 1:2 with window glazing that is 20% of the external wall area. All case studies use energy-saving controls for artificial lighting and efficient lighting fixtures. The ETOB has a more sophisticated high-tech lighting systems.

Acknowledgment

My great appreciation goes to Ms. Laila Al-Rais

(Architect, the Executive Design Bureau, The Executive Office, Dubai) for her great assistance in collection of data and surveys, communication with resources, and coordination tasks with the author. Special thanks goes also to all the people who provided valuable information to this research: Mr. Mansoor Al Dabal (General Manager, Engineering & Projects, Dubai World Trade Centre), Mr. Wafa Ezzo, (Project Manager, APG), Mr. Hani Faraj (Structural Engineer, APG), Mr. Andrew Hornsby (Estate Manager, Emirates Towers), Ms. Judith Thomson (Marketing & Administration Manager, Emirates Towers), Mr. George Gordon (Group Director of Facilities Management, Jumeirah International), Mr. Manu Jeerakun (General Energy Director, Engineering Department, Jumeirah International).

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