BEDP ENVIRONMENT DESIGN GUIDE

LOW-ENERGY DESIGN IN THE UNITED ARAB EMIRATES

– BUILDING DESIGN PRINCIPLES

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Climate responsive design and traditional design elements of the Persian Gulf may provide a basis for low-energy design. Current building models employed in the United Arab Emirates are often unsuited to the region's climate, causing massive cooling loads as a result of inappropriate site planning, orientation and building envelopes with high levels of glazing. The application of an inter-disciplinary design approach that considers urban design, landscape design, architecture and meteorology may provide a more appropriate low-energy design for such hot and arid climate

Keywords:
arid climate, climate responsive design, environmental design strategies, low-energy design, UAE, United Arab Emirates

1.0 INTRODUCTION

The United Arab Emirates (UAE) provides a unique opportunity and challenge for architects and other design professionals to develop a new low-energy urbanism and architecture. The UAE is currently the worlds' largest user of energy on a per capita basis, with 70 per cent of primary domestic energy usage being committed to buildings, primarily in the form of mechanical ventilation (air-conditioning and heating) and artificial lighting (Kazim, 2007). In the case of low-rise buildings between 37 per cent and 80 per cent of energy consumption can be for cooling (Aboulnaga, 1998).

Countries of the Middle East such as the UAE possess a rich architectural legacy based upon climate responsive design. Diminishing oil supplies in some Emirates within the UAE have lead to a diversification of the economy expressed in dramatic levels of building and infrastructure development. This ongoing strategy of economic diversification coupled with a desire by government and developers for market differentiation, the UAE's commitment to the Kyoto Protocol and a changing regulatory framework, are providing the opportunity for the UAE to become a centre of research, experimentation and development of low-energy solutions for building and urban design. This can already be seen in projects such as Masdar in Abu Dhabi, a proposed zero energy city and research hub designed by Sir Norman Foster, based upon traditional planning principles of the "walled city" (Foster + Partners, 2008, Masdar Initiative, 2008).

Traditional architecture in the Gulf region is based upon a sophisticated response to climate that employs passive techniques for the cooling and heating of urban spaces and buildings. Australia shares a similar hot and arid climate across much of the country and employs many low-energy strategies that originated in the Gulf region, such as the courtyard, or 'courthouse' building model (as they are known in the Middle East and North Africa), that can be seen here, which respond to the problems of solar radiation and hot winds.

Contemporary buildings in the UAE are often based upon imported building models unsuited to the climate and culture. These solutions can only function through extensive intervention by mechanical air-conditioning leading to disproportionate usage of oil and natural gas reserves and consequently high levels of carbon emissions.

This paper identifies passive design strategies that may contribute to a low energy architecture in the UAE, and the companion paper discusses urban design strategies. The severe climate and market expectations within the UAE require the use of HVAC systems in most cases. Building design that responds to the climate can complement active systems through reducing building energy usage and associated carbon emissions, whilst contributing to an appropriate vernacular architecture and forming a legitimate starting point for architectural expression relating to place and lifestyle. The goal of these guidelines is that they can contribute to the education and awareness of architects and clients and be incorporated into organisation practice management systems.

1.1 GUIDELINE SCOPE

Climate responsive design can be equally applied to all building types and scales and so this guideline is intended to be generic, applying to high-rise and low-rise construction. The proposed design strategies are primarily relevant to passive considerations such as floor planning, façade design and orientation and not those driven by engineering solutions such as co-generation. Strategies are focused on the reduction of cooling loads in buildings, as this represents both the bulk of energy usage and the fastest growing energy demand in the UAE, where the cooling season is much longer than the heating season.

The research and case studies for low-energy design in the UAE are still developing and so this report draws from a wide range of sources including recent academic papers and media articles in addition to established literature by authors such as Baruch Givoni, (architect and climatologist), Hassan Fathy (noted Egyptian architect) and Richard Hyde (coordinator of architectural and design science discipline at Sydney University) that analyses building in other similar hot and arid climates of the world.

Givoni's urban and building design strategies developed over the last thirty years are focused on providing low-cost residential accommodation for the developing world, where air-conditioning may not be affordable. Although since that time the economic growth of some of these countries such as the UAE has increased rapidly, and air-conditioning is becoming an expected part of contemporary building, Givoni's focus on low-energy solutions is equally applicable today.

2.0 GENERAL BUILDING DESIGN STRATEGIES

Energy conservation in building design can be achieved by firstly minimising the energy needs through correct building design such as glazed to opaque wall ratios and thermal mass; and secondly by maximising the use of available natural energy sources for cooling such as use of prevailing breezes.

> *"The most effective way to reduce building services energy consumption is to exploit natural means and depend less on mechanical techniques" (quoted from Farmer, and Guy in "Visions of Ventilation" in Boeke, 2008)*

2.1 BUILDING ORIENTATION

Building orientation can provide reductions to cooling loads through minimising solar penetration through windows, minimising solar absorption through walls and roofs, and by maximising cross ventilation. The latitude and high insolation levels of the UAE lead to the highest intensity of solar radiation being on the east and west facing walls in summer and the south wall in winter. This promotes a strong preference for the north south orientation of main facades and glazing. Simple window shading is easy to facilitate as a result of the high solar altitude and greater reflection of solar radiation from the façade due to the lower angle of incidence.

The higher levels of humidity between the cooler months of December and March also require orientation to suit prevailing wind directions. Even if breezes are not perpendicular to a façade, oblique wind angles as low as 30°C to the wall face can be beneficial for cooling if coupled with cross ventilation to a leeward wall. Orientation can also be considered in the internal planning of spaces to ensure rooms benefit most from ventilation, such as living and sleeping spaces addressing prevailing breezes and the use of extended party walls and vertical window blades to improve air movement by acting as wind scoops, and thus increase air movement to the interior.

Orientation can provide the major driver of elevational design in high rise construction, in contrast to current common practice where un-differentiated facades offer no meaningful way for buildings to respond to climate. The resultant inefficiencies are magnified in the UAE where climatic conditions are extreme, and lead to substantial heat gains.

Given the low altitude of early morning and late afternoon sun, east and west facades if made opaque can serve as thermal mass buffers. The south, being the most solar exposed orientation in the northern hemisphere, requires solar access and glare to be carefully controlled. North facing facades, however, provide an opportunity for a more open façade which can admit controlled daylight and provide views, whilst minimising solar heat gains. Some shading may be required to northern façades to address late summer afternoon sun (Baker, Steemers, 2000, Givoni, 1998).

2.2 PLANNING AND BUILDING TYPES

The choice of building type will impact its climatic performance, energy usage and thermal comfort. Consequently differing building types provide varying advantages and disadvantages and require differing strategies (Givoni, 1998).

2.2.1 High rise buildings (typically commercial / hotel / residential)

High rise buildings are considered to consume the highest level of energy due to their higher embodied energy, higher energy consumption due to cooling, lighting and lifts, and higher energy consumption for maintenance and cleaning (Bahaj, et al, 2008, Wood, 2007, Givoni, 1998, Hausladen, et al, 2005). The levels of solar radiation and resultant heat loads are also the highest due to the lack of shading available from other buildings, climatic exposure and the reflection from roofs of lower buildings. Increased wind pressure constrains the use of external sun shading and operable windows beyond a certain height. The height of high-rise building limits their ability to take advantage of passive design features, resulting frequently in buildings which are largely sealed, thus requiring mechanical services for environmental control.

While high rise buildings will typically be air-conditioned, cooling loads can be reduced through the use of natural ventilation in cooler months. High rise buildings enjoy the greatest ventilation conditions of all building types due to the generally higher wind speeds above the urban canopy and the increase to wind speed with height (Givoni, 1998). In order to take advantage of this additional air movement a number of techniques need to be considered to avoid excessive drafts and wind damage. These include the use of double skin facades (discussed below), correct selection of window types, the use of heavy-duty friction hinges and directing cooling breezes through conduits in concrete floor slabs, thereby providing 'free' cooled air.

Cooling loads can be further offset by the harnessing of wind for energy generation, increased performance of thermal buoyancy in façade cavities, atria and voids and typically higher thermal mass from massive building structure and envelope (Wood, 2007, Givoni, 1998). Examples of buildings that incorporate such strategies include the Pearl River Tower in Guangzhou and the Bahrain World Trade Centre, which incorporate large wind turbines into their façades.

The energy performance of multi-storey apartment buildings is dependent upon the organisation of dwellings and circulation. Double loaded corridor arrangements (being those with apartments to both sides of a central corridor), are not suitable for low-energy design in this climate due to the poor ventilation characteristics. Air conditioning will typically be required for large periods of the year, however, can be offset by natural ventilation when outside conditions are able to provide indoor comfort.

2.2.2 Low rise buildings (typically residential)

SINGLE-LOADED CORRIDORS

Single loaded corridor buildings are suitable for the climate, where a glazed or screened corridor can be opened or closed to suit outside temperature conditions, thus allowing cross ventilation. Providing windows to corridors may compromise resident acoustic and visual privacy, but this can be partly addressed through the introduction of air shafts above corridors or the lowering of the corridor floor height below that of the apartment floor height, as shown in Figure 1.

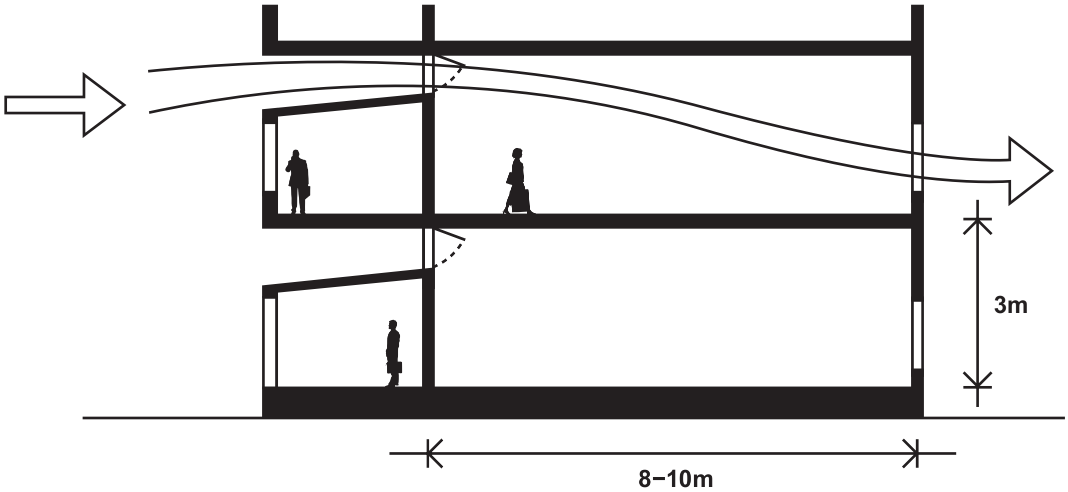

Figure 1: Natural ventilation with single loaded corridors

(Adapted from Givoni, 1998)

MULTI-STOREY APARTMENTS WITH TWO OR MORE APARTMENTS PER STAIRCASE

Buildings where two or more apartments are clustered around staircases can provide better climatic outcomes than single loaded corridor solutions. Each apartment features two opposite external walls, providing the potential for cross ventilation. This building type also has the advantage of maintaining acoustic and visual privacy and therefore provides the most suitable model for energy reductions in this climate (Bahaj, et al, 2008, Wood, 2007, Givoni, 1998, Hausladen, et al, 2005). The provision of more than three units per staircase may cause wind shadows resulting in poor ventilation and are therefore not suitable for cross ventilation.

DETACHED HOUSING

Detached houses feature a large envelope area and are therefore highly susceptible to solar radiation. This means that detached housing can be the most energy demanding building type when air-conditioned. This can be offset by their greater capacity for natural ventilation as they are more able to take advantage of wind from any direction. The roof element is highly exposed to solar radiation in hot and arid climates, typically located in low latitudes where the sun's elevation is high. Strategies such as roof monitors and ponds can provide passive cooling and day lighting thereby reducing the need for air-conditioning and artificial lighting. In this way the roof becomes an energy source rather than an energy load (Givoni, 1998).

TOWNHOUSES

Townhouses feature smaller building envelopes and less exposed façades and so have corresponding lower cooling loads. They are more sensitive to orientation than detached housing, however if properly designed can provide greater energy reductions than detached houses in this climate. Row buildings can also harness the potential for natural thermosyphonic ventilation or the "chimney effect" at night time, which is facilitated by voids through multiple storeys. Townhouses combine some of the advantages of multi-storey apartments such as reduced external wall area and thus heat gain, with those of detached houses, such as greater access to natural ventilation (Bahaj, et al, 2008, Wood, 2007, Givoni, 1998, Hausladen, et al, 2005).

2.3 BUILDING PLANNING AND VENTILATION

The configuration of the floor plate can provide reductions to cooling loads by reducing heat gains and promoting cross ventilation in the 6 months of the year when favourable temperatures prevail. Lower A/V ratios (ratio of external surface area to volume), result in lower heat gains and consequently reduced energy usage.

AIR-CONDITIONED

In the case of buildings cooled primarily by air-conditioning, the floor plate should be compact to minimise solar heat gains and radiated heat gains from the urban environment.

NATURALLY VENTILATED

Buildings designed to minimise cooling loads primarily through the use of natural ventilation may incorporate a flexible floor plan that enables a compact shape, whilst allowing modifications that achieve a spread out plan with greater exposure to the air. This can be achieved through the use of a compact floor plan which contains perimeter courtyard and balcony indents. These courtyards can be sealed by shutters or opaque panels during the day time and opened at night time. The changeable surface area of the building envelope both minimises the day time radiant and conductive heat gains and maximises the rate of cooling via cooler night time air movement.

This ability to be able to open the floor plan more fully also provides benefits during periods of high humidity, which call for greater natural ventilation (Aboulnaga, et al, 2000, Givoni, 1998, Hausladen, et al, 2005). The depth of the floor plan should also be designed to ensure suitable daylighting levels. Tools such as the Woods Bagot Daylighting Tables can be used for this purpose (Woods Bagot, 2007).

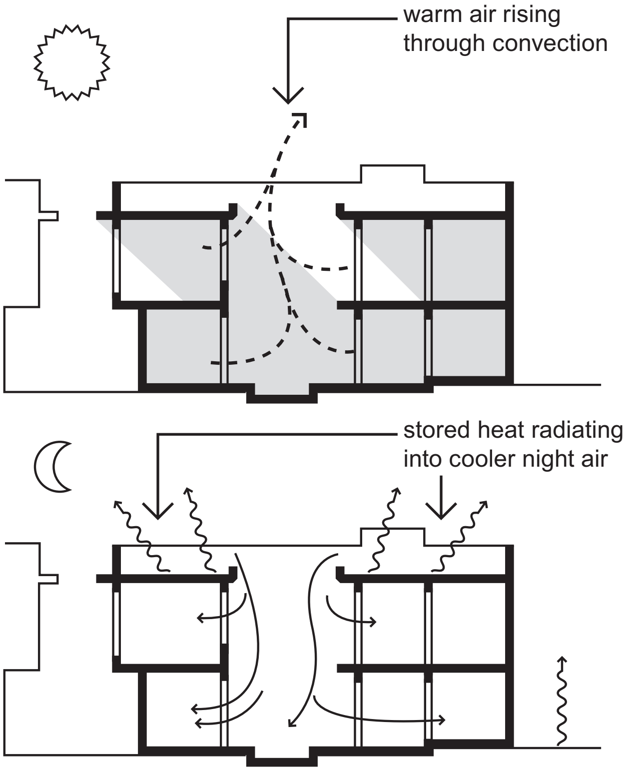

Figure 2: Day versus night response of courtyard building

(Adapted from Koch-Nielson, 2002)

2.4 COURTYARDS

Central courtyards can reduce cooling loads by facilitating additional natural ventilation to the building and providing a source of cooler air from the micro-climate created by shading elements, vegetation and evaporative cooling from ponds and water sprays. Courtyards create voids and thus shelter from hot winds, whilst allowing hot air within the adjoining spaces to be vented via convection.

Courtyards also enlarge the surface area of the building and so can lead to faster rates of heating if not designed appropriately. The introduction of the cooled air at night time combined with the use of double glazing to reduce day time heat gains can cool the building interior in preparation for the next day. Studies have demonstrated that courtyards can provide the greatest energy efficiency benefits in hot dry and hot humid climates such as the UAE (Aldawoud, 2008). Courtyards can also provide additional daylighting levels and so reduce dependence upon artificial lighting. Street courtyards with shade tree planting can also provide cooling benefits to street areas and adjacent building interiors (Safarzadeh, Bahadori, 2005, Shashua-Bar, Hoffman, 2004).

2.5 BUILDING COLOUR

Building envelope colour can influence thermal performance and reduce maximum indoor temperatures, thus reducing the need for mechanical ventilation and cooling. White surfaces absorb less solar radiation than dark surfaces, thus transferring less heat to internal surfaces by conduction and to indoor air through convection. The amount of solar radiation reflected varies from 80 per cent in the case of white surfaces, to 20 per cent in the case of black surfaces.

In order to avoid glare, medium light colours can be used for selected walls and projecting elements such as balconies can be finished in darker colours, whilst also casting shade on to light coloured walls. This strategy is most effective in high solar radiation conditions as demonstrated in the UAE and represents a simple and cost effective technique for reducing building energy use (Cheng, et al, 2005, Givoni, 1998), albeit not adequate for contemporary air-conditioned structures.

2.6 INSULATION

The insulation of roof, wall and window elements can significantly reduce cooling loads of buildings in hot and arid climates. Walls should be provided with minimum R values (measure of thermal resistance) of R2 to R3 and roofs R5. The performance of glazing can be improved through the use of Insulating Glass Units (IGU's). Standard IGU units consist of 2 panes of regular glass which are separated by an air space, can achieve an R-value (which is a measure of the efficiency of insulation) of R-2. Triple glazed units consisting of low-emissivity glazing and gas filled air cavity can achieve an R-value of R-5 and quadruple glazed systems featuring heat mirror films inside an IGU and can achieve an R value of R-12.5 (Southwall Technologies, 2009). The Dubai electric company estimate that building power requirements can be reduced by up to 40 per cent through the use of thermal insulation systems, which are mandatory in Dubai (Polystyrene products Industry, 2009).

2.7 THERMAL MASS

Thermal mass in buildings can reduce cooling requirements in both low-rise and high-rise construction particularly when taking into account usage patterns. High thermal mass in external walls and roofs can slow down the heat transfer through the envelope and so can be particularly effective in office buildings which are un-occupied at night time. External air temperatures are then cooler and so the building interior can be cooled by natural ventilation and mechanical ventilation, in preparation for the next day. Insulation should also be provided within the wall cavity or to the external surface of the wall. External night time temperatures are above the desirable comfort band for a maximum of 6 months of the year, thereby limiting the application of this strategy to the cooler months. Internal thermal mass provided in floor and ceilings/soffits can absorb and store heat generated internally from office equipment and people and from penetrating solar radiation, thereby reducing air temperature elevation.

An alternate strategy of providing, low mass construction may be selected in buildings un-occupied during the day such as in the case of some residential applications. The maximum indoor temperature would occur in the afternoon and rapid cooling can be achieved during the evening with natural ventilation (Baggs, Mortensen, 2006, Cheng, et al, 2005, Givoni, 1994, Prelgauskas, 2003, Yilmaz, 2007). Thermal mass has been demonstrated to provide up to 27 per cent of building cooling benefits in a commercial high rise building in other arid climates such as Perth (Baggs, Mortensen, 2006).

2.8 SHADING

Shading of windows in hot and arid regions is more important due to the higher levels of solar radiation than in any other climate type. This is exaggerated in cities where solar radiation is reflected by the wall and roof surfaces of neighbouring buildings and where long-wave emission from the surrounding ground is increased due to the lack of vegetation and light desert colour. Architectural shading can include correct orientation and opening sizing as well as colonnades, balconies, roof overhangs and planted mesh. The most effective forms of protection are fixed and external operable shading devices designed to suit the orientation.

Fixed shading strategies can include horizontal overhangs to south elevations, 'egg crate' fixed to east and west elevations and vertical fins to north elevations where they require shading of late afternoon sun. The effectiveness of fixed shading devices in desert regions is limited due to the high levels of reflected solar radiation and the high air temperatures that extend into autumn and spring, when the sun may be low enough to strike even shaded window areas.

Operable shading devices can be adjusted to exclude or admit direct or indirect solar radiation while permitting natural ventilation. Devices may include adjustable blades, louvred shutters or insulated shading panels. Insulated panels provide the further benefit of increased thermal resistance when closed. Operable shading devices are most effective in hot and arid climates where they can reduce solar heat gain through windows by 85-90 per cent, while still permitting daylighting to enter (Givoni, 1998).

Shading devices should be made of light and reflective materials to avoid re-radiation of heat. They should be configured to avoid the trapping of hot air against facades, and prevent reflection of solar radiation onto walls or other windows (Koch-Nielsen, 2002).

2.9 FACADE DESIGN

The building façade plays the principal role in the overall energy performance of a building, controlling heat transfer, solar radiation and airflow. In a hot and arid climate the key strategy is to control heat gain by avoiding penetration of solar radiation, while allowing reasonable daylighting levels and views. The orientation, placement and size of windows largely determines the heat gains, with up to 80 per cent of total energy use in typical UAE residential buildings being used for cooling (Aboulnaga, 2000).

Strategies for low-energy design are described in two categories. Firstly high rise buildings which more typically incorporate larger areas of glazing, and secondly, low rise buildings which commonly incorporate more opaque walls with smaller openings, more consistent with a traditional regional form of building.

3.0 BUILDING TYPE SPECIFIC STRATEGIES

3.1 HIGH RISE BUILDINGS

The amount of solar radiation admitted into a building interior is directly proportional to the ratio of glazing to opaque wall (Hausladen, 2005). The extent of glazing employed in facades in European and North American buildings is based upon significantly different climate conditions that assume lower outdoor temperatures and daylight levels. Extremely high levels of solar radiation and clear skies in the UAE provide an entirely different design environment, and mean that highly glazed facades are inappropriate.

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Opaque facades are more effective in lowering cooling loads than highly glazed facades. Extreme external daylight levels in the UAE frequently lead to excessive daylighting and glare in highly glazed buildings and so greater façade opacity can provide a further advantage (Aboulnaga, 2006).

> *"Reducing cooling load can best be achieved, in approximate order of effectiveness, by using opaque wall elements, shading and/or solar control coatings. Many analyses of DF's [double façade] begin with the assumption that 100 per cent of the vertical enclosure must be transparent. This eliminates the possibility of the most effective means of reducing cooling loads".*
>
> *(Boake, et al, 2008)*

3.1.1 Glazing

Heat gain through large areas of glazing can be mitigated by external shading and through the use of heat insulated and solar control glazing, however will often lead to glazing with high levels of reflectivity. This may have the undesirable effect of transmitting additional solar radiation and heat loads into the urban environment and onto other buildings. Other strategies beyond more common practice of low-e (insulating) glazing for decreasing heat transmittance through glazing may include innovative glazing technologies such as:

Aerogels glazing: a super low density solid developed by NASA, which feature a minimal U value (a measure of how well an element conducts heat), and these are now available on the commercial market in the region.

Vacuum glazing: incorporates two sheets of glass, separated by a narrow space evacuated of air. Glazing is treated with a low emittance coating providing similarly low U values to that of aerogels and while further developed, is being viewed cautiously by the market.

Electrochromic glazing: provides a variable tint which can be controlled by the user or a Building Management System, to reduce solar gains. Cooling loads can be reduced by up to 26 per cent, however user acceptance and outstanding technical issues have prevented market penetration to date.

Photovoltaic facades: feature silicone wafer solar cells integrated into glazed panels and also provide some shading potential. Although these facades may re-radiate heat to the interior of the building, they are predicted to provide a net energy gain over air-conditioning loads where covering 40 per cent of the façade (Hausladen, 2005). Studies by the University of Southampton predict that such glazing types may provide substantial improvements to solar control and daylighting characteristics to high rise buildings in the UAE, in comparison to solar control and low-e glazing which are the current industry standard (Bahaj, et al, 2008).

> *"Green glass towers as a design concept is flawed both mythologically and technically. Moreover green glass towers provide dangerous exemplars to lesser designers, or developers with budgets of more modest proportions. The possibility of uncritical replication of this aesthetic following iconic design procedures, without sufficient consideration of the complex environmental problems inherent to the glass tower, render an alliance of ecologically responsible design and glass tower a risky proposition "*
>
> *(Boake, et al, 2008).*

Other strategies for reducing cooling loads include introverting the glazed walls into sky gardens (aerial courtyards), as employed in the National Commercial Bank in Jeddah. Outer screens can be employed to shade the glazing such as the fretted stone screens employed in the Dayabumi Complex in Kuala Lumpur and as commonly used in traditional building forms (Fathy, 1986). Employing orientation as a key strategy suggests facades should be differentiated to suit the differing solar and ventilation characteristics of each elevation.

3.1.2 Double-skin facades

Double skin facades consist of an external façade, an intermediate space and an inner façade. They have the potential to reduce cooling loads from those of conventional curtain glazed facades, through enabling high rise buildings to benefit from the same energy efficiency and passive cooling strategies more commonly applied to low rise buildings. Studies have demonstrated this to be effective in both moderate and hot and humid climates (Wong, et al, 2008).

As mentioned above, the increased wind velocities experienced by high-rise buildings often limit the provision of openable windows (and thus natural ventilation), and the provision of shading devices. By using a double-skin façade, the intermediate space provides a protected location for sun shading systems, decreases solar radiation transmission to the building interior and permits thermal buoyancy which can provide natural ventilation to the interior and exhaust hot air from the cavity and building interior. In the case of the UAE, double skin facades maybe beneficial in allowing the use of external sun shading, not otherwise permitted due to dust storms and high wind velocities. Double skin facades have been built in other climate zones such as Beijing where they provide protection from frequent dust storms and other air pollution, and thus reduce the need for cleaning of horizontal elements. Night time 'purge' ventilation may be considered during the cooler seasons at times when dust storms do not provide a hazard. This can provide cooling of the internal thermal mass, thereby reducing the cooling loads of the building's HVAC system during the day.

The literature is divided on how effective double skin facades are in providing energy savings in hot and dry climates. However there is evidence that they can provide reductions in cooling loads when expertly designed and installed, where compared to other highly glazed buildings with single glazing and low-E glass. Studies on behalf of the UK Department of Environment have shown that double skin facades are able to reduce energy usage by 65 per cent and reduce CO2 emissions by 50 per cent in cold temperate climates, and 30 per cent in other studies (Haggag, 2007). Information on the performance of double skin façades in hot and arid climates is not available to the same extent as for temperate climates where their usage is more common. Studies have been completed in hot and humid climates such as Hong Kong by Haase, indicating that a double skin facade can reduce cooling loads to a varying extent, dependent upon the glazing types, typically between 14 and 20 per cent (Haase 2006). Oesterle suggests that where the principal energy requirement is for cooling, improvements of 10 per cent are achievable when compared to a single skin glazed façade (Oesterle, et al, 2001).

The performance of double skin facades are commonly rated against conventional single skin glazed façade. This does not recognise that the most effective strategy of reducing cooling loads is reducing the ratio of glass and increasing the ratio of opaque cladding. The reduction of Window to Wall Ratios (WWR) from 91 per cent (a conventional single skin glazed façade) to 32 per cent (mixture of solid spandrels and single glazed band windows) can reduce the cooling loads by 15-20 per cent. Strategies that involve the reduction of WWR and the provision of a double skin façade can reduce cooling loads by up to 27 per cent in hot and humid climates (Haase 2006).

The further benefit that double skin facades can offer is in requiring less reflective glazing, thus avoiding the reflection of solar radiation to adjacent buildings and streets that would otherwise increase urban heat gain (Oesterle, et al, 2001, Haase, Amato, 2008).

3.2 LOW-RISE BUILDINGS

3.2.1 Thermal Mass

Vernacular architecture in the UAE employs the principles of thermal mass and small windows to minimise heat gains. While this can successfully mitigate day time temperatures to an acceptable level, internal conditions at night time could become uncomfortable due to elevated temperatures resulting from the thermal lag (the time required for heat to permeate) of walls and roofs. The traditional solution to coping with this was for occupants to sleep on the flat roofs or in courtyards, a practice that would not be acceptable today due to the greater influence of modern western standards.

The application of this traditional strategy of minimising day time ventilation and utilising dense materials for roofs, walls and floors combined with high levels of external or cavity insulation, will insulate the interior and even out the diurnal temperature range.

3.2.2 Operable Shutters

Thermal comfort can be further improved by employing large openable windows and insulated shutters. These can provide both shade during the day and ventilation at night, to increase the rate of cooling of the interior. These openings should be placed to the windward and leeward facades so as to allow for maximum ventilation when conditions are acceptable. Small glazed panels can be incorporated into shutters to provide daylighting and views or adjustable louvres may provide a similar result. Another strategy may be to only provide shutters in sleeping spaces, unoccupied during the day.

3.2.3 Small Windows

Where large openings cannot be employed, studies indicate that limiting window size and locating windows to only two elevations will reduce the energy consumption by approximately 55 per cent (Fathy, 1986). The ratio of glazing should be limited to 10-20 per cent of the surface area of those walls and shading should be employed (Aboulnaga et al 2000).

3.2.4 Lightweight Construction

Highly insulated lightweight roofs and walls can also be employed where the building is not occupied during the day, thus ensuring rapid heat loss by natural ventilation or mechanical cooling when required, such as in the evening when the building is occupied.

3.2.5 Elevated Living/Sleeping Areas

Locating living and sleeping spaces to upper levels with larger openings, allows the advantage of higher wind velocities that exist above the height of tree canopies (Givoni, 1976, 1994, 1998).

3.2.6 Daylighting

The use of daylighting can reduce building energy usage by displacing the electrical energy that would otherwise be used to provide artificial lighting and by reducing the cooling loads generated by the lighting fixtures (Baker, Steemers, 2000). Internationally daylighting can account for 50 per cent of energy requirements in commercial buildings and the proper use of daylighting, high performance lighting and correct glazing selections can provide 30-50 per cent reductions in lighting energy (Aboulnaga, 2006). External daylighting levels in the UAE are extremely high, varying from 75,000 to 107,500 lux, while the lighting levels required inside buildings at the working plane are 300 to 2000 lux (Aboulnaga, 2006). This is in contrast to overcast skies in cool climates that provide even and diffused daylighting, permitting much higher glazing ratios. Consequently window placement, glazing type and ratio are crucial to effective energy efficient lighting, with windows ideally representing 25-40 per cent of the external wall area. It is not uncommon for commercial buildings in the UAE to use glazing ratios of 80-100 per cent, a practice unsuitable to the climate and a major contributor to excessive energy usage. High daylight levels also permit the use of deeper floor plans, up to 19m from the façade to the building core or mid-point of the floor and reduced reliance upon artificial lighting (Baker, Steemers, 2000, Majoros, 1998, Woods Bagot, 2007).

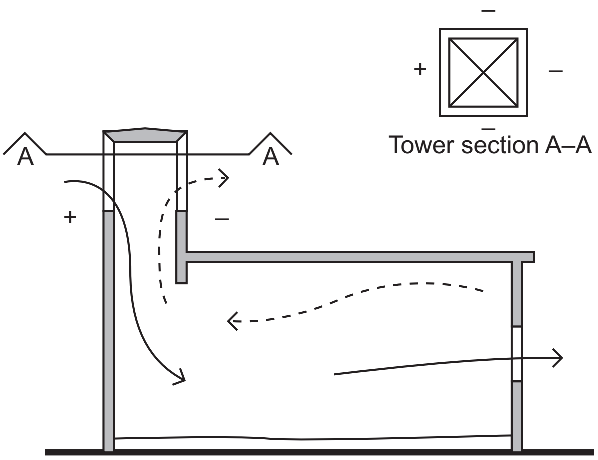

Figure 3: Traditional wind tower
Showing air pressure differentials
(Adapted from *Stay Cool* by Koch-Nielsen)

3.2.7 Shading

The new Abu Dhabi Building Code and the Estidama System are considering mandatory external shading to buildings. The new Abu Dhabi Planning Framework is also planning mandatory street shading in certain precincts. These types of policies, while good for energy consumption, need to be assessed for their impacts on daylighting in buildings,

3.2.8 Wind towers

Wind towers or wind catchers have been used in the UAE, Iran and neighbouring countries for centuries, for natural ventilation and passive cooling of buildings. Vertical shafts are provided with high level shaded openings, orientated towards the prevailing wind directions, which catch breezes and push them into the rooms of the building below. The height of the tower openings provides access to cooler and cleaner air of a greater velocity. Wind towers make use of differential air pressure to achieve natural ventilation to the rooms below by increasing the air circulation (air velocity and air changes) without admitting solar radiation. The increase in airflow increases the convective heat loss from the body by instilling evaporation. (Coles 2006, Givoni 1998).

Wind towers may provide low-energy solutions in some applications for low rise developments, incorporating night ventilation in summer and day time and night time ventilation during the cooler season. Analysis of climatic data of the UAE suggests the use of day time ventilation may be limited to the months of December to February and night time ventilation to the months from November to April (Bahadori, Mazidi, Dehghani, 2008, Baker, Steemers, 2000, Coles, Jackson, 2006). Wind towers are also subject to poor performance in turbulent air conditions that typically exist in urban conditions as the flow of air in the vertical shaft can be interrupted by relatively low back-pressures. Modern wind towers are often equipped with mechanical fans to improve the movement of air and compensate for changing wind and temperature conditions. Inlet and outlet openings are required to be between 3-5 per cent of the floor area served (Koch-Nielsen 2002).

4.0 CONCLUSION

The traditional building design practices of the Gulf region, based upon an understanding of climate, provides a foundation for low-energy buildings in the UAE today, that is appropriate to the environment and results in reduced carbon emission. This may also lead to an appropriate contemporary vernacular architecture, that can replace imported building models that have contributed to a dramatic rise in energy usage and a proliferation of culturally non-specific building forms (Bouman, Khoubrou, Koolhaas (eds), 2007).

Significant generic literature exists to support education in the design of low-energy buildings in hot and arid climates, complemented by regional journals and research papers that have measured the benefits of traditional design strategies and the poor performance of imported models, in particular those incorporating curtain glass facades. The dramatically different climatic conditions of the Gulf region mean these imported solutions can only function through extensive intervention by mechanical air-conditioning.

Strategies for low-energy design for buildings include orientation, the use of thermal mass, insulation, external shading, traditional wind towers and various façade solutions that favour a greater use of opaque material than in temperate climates.

The benefits of employing traditional design principles such as high thermal mass are accompanied by deficits, such as uncomfortably high internal night time temperatures, which would be considered undesirable by current cultural and industry standards. Lessons from vernacular architecture need to be integrated with current technologies in, for example, mixed mode buildings, in order to be successful and accepted in the market.

The rate of development in the UAE has demonstrated the economic and lifestyle opportunities that exist within the region, despite the harsh climate. Architects such as Rem Koolhaus see the UAE as a unique opportunity for urban designers and architects, stating in Al Manakh:

> *"The Gulf's entrepreneurs are reaching places that modernity has not reached before….Perhaps the most compelling reason to take the Gulf seriously is that its emerging model of the city is being multiplied in a vast zone of reduced architectural visibility that ranges from Morocco in the West, then via Turkey and Azerbaijan to China in the East. In each of the countries of this Silk Belt, the Gulf's developers operate on a scale that has completely escaped "our" attention. The burgeoning campaign to export a new kind of urbanism – to places immune to or ignored by previous missions of modernism – may be the final opportunity to formulate a new blueprint for urbanism"*
>
> *(Koolhaas, 2007).*

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