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THE AL BAHR TOWERS – ENHANCING SUSTAINABILITY THROUGH INNOVATION

K. Xuereb[1]
[1] Arup, 13 Fitzroy Street, London W1T 4BQ, United Kingdom
Tel: (+44) 02077555443, Fax: (+44) 02077553743
Corresponding Author E-mail: konrad.xuereb@arup.com

ABSTRACT: This paper presents the Al Bahr Towers recently completed in Abu Dhabi. It describes the innovative adaptive facade that wraps around the towers and adapts in accordance to the solar incidence to control solar heat gain and optimise daylight within the buildings. The paper reports the studies carried out to mitigate the risks inherent in implementing a novel shading system in a large building project. It elaborates on how the façade was implemented and its sustainability credentials in relation to energy performance of the project. The paper describes how daylighting was controlled by the Mashrabiya screen and the typology of the curtain wall lying behind it. A critique is made on the possible implementation of a similar system in a Mediterranean climate.

Keywords: Al Bahr Towers, Mashrabiya, Sustainability, Innovation

1 INTRODUCTION

The Al Bahr towers, located in the financial centre of Abu Dhabi, comprise two quasi-identical, 26-storey, 150m tall buildings. See Figure 1. The towers are the latest addition to Abu Dhabi's ever-changing skyline and their architecture embraces Islamic geometric patterning. They feature an innovative dynamic shading screen, the Mashrabiya, which enhances the sustainable criteria of the development by optimising the use of natural daylight whilst controlling solar heat gain.

Figure 1: View of the towers from the North

The award-winning project was conceived by the Abu Dhabi Investment Council (ADIC) during a period of intense construction activity in the UAE that also saw a regional drive towards implementing sustainable measures in building projects. The current stock of construction in Abu Dhabi, including Masdar city, reflects its intent to become a world city in a post fossil-fuel age.

Following an international design competition in 2008 the design bid submitted by London-based architect Aedas, together with Arup as multidisciplinary engineering designer, was chosen as the winning entry by the client body. Arup was involved from the competition through to the construction stage, providing the full range of design services and specialist advice, from the core disciplines of SMEP (structural, mechanical, electrical, public health) engineering to specialisms like environmental physics and advanced technology. Construction began in March 2009 and was completed in early 2013.

2 PROJECT DESCRIPTION

The site is located in the south-east part of the Abu Dhabi city peninsula, at the junction between Al Salam Street (8th Street) and Al Saada Street West (19th Street), in a zone allocated for business developments by the city's authorities.

The two towers are primarily designed for office use but also contain ancillary space that includes auditoria, prayer rooms, plant rooms and a gymnasium. They share a two-storey basement that functions predominantly as a car park and includes several large plant areas, a secure vault, and various back-of-house areas.

Between the towers, a 100 m wide curved roof forms a shallow dome over the entrance podium, its front partially glazed and forming a dramatic entrance to the buildings. Visitors enter this fully conditioned space and can proceed directly to either tower (Figure 2). The podium incorporates the grand entrance lobby, a 200-seat auditorium, male and female prayer rooms, back-of-house areas, two restaurants with associated kitchens, and plant. A mezzanine floor is hung from the front edge of the overlying foyer roof. This space forms the cafeteria area and is directly above the heavily glazed main entrance. Solar panels at podium level are used to preheat the hot water supply for the buildings.

Figure 2: Podium and mezzanine between towers

Both towers incorporate multiple-storey skygardens over part of their perimeters. These act as buffer zones between the office space and the external environment along the height of the towers. The crown, a vaulted observation level, tops each tower and offers spectacular views of the surroundings.

Figure 3: Traditional shading screens used in vernacular Islamic architecture

A key design driver was to develop a building envelope that was both efficient and iconic, related to Islamic architecture and also embodying a novel approach to reducing the effects of the high ambient temperatures and intense solar radiation that characterise the local environment. The innovative idea was to develop an external movable shading system, the "Mashrabiya", named after the form of shading screen that had been used for centuries in Islamic architecture. See Figure 3.

2.1 TOWERS

The towers are elliptical on plan and cylindrical in section. A centrally located, 20 m diameter, core provides lateral stability to each tower. The core accommodates passenger and goods lifts, together with ancillary rooms, storage and plant equipment, thus freeing the floor plates for office use. The repetitive core layout enhanced efficiency and facilitated the construction process.

Figure 4: Construction of towers, showing recesses in floor plates to form the skygardens

The perimeter structure consists of steel columns following a honeycomb geometry to fit the architectural concept. See Figure 4. The trussed nature of the perimeter structure contributes approximately 10% of the superstructure's overall lateral stiffness. The geometry of the perimeter structure also adds resilience under accidental loading by providing alternate load paths to adjacent perimeter columns.

Primary steel beams span radially between the concrete core and the perimeter steel columns, and edge steel beams connect into the perimeter columns. The trapezoidal floor plates are formed by thin composite floor decks. The steel beams cantilever beyond the edge beams to form connecting positions for the supporting arms of the Mashrabiya (Fig 5).

Figure 5: Mashrabiya installed onto supporting steelwork

The tower floor plates outside the cores accommodate open-plan office space, cellular offices and meeting rooms. These areas are provided with ventilation and cooling from a concealed fan coil unit system distributing tempered air to the occupied zone. Detailed co-ordination of the services integrated in the suspended ceiling (including grilles, lighting, sprinkler heads, smoke detectors and occupancy sensors) resulted in an elegant system that both allowed straightforward installation and enables adaptability to future layout changes.

Level 17 is designated as a plant floor and contains ventilation plant equipment for tower accommodation, additional water storage, intermediate chilled water pumps and associated electrical switching and life safety equipment. Additional ventilation plant levels 27 and 28 serve the crown and executive areas. Two central AHUs at level 17 provide tempered outside air to individual fan coil units at each level; the AHUs incorporate heat recovery devices to reduce the duty associated with cooling warm humid outside air to suitable supply conditions. Heat is effectively recovered from both general accommodation extract and WC extract.

The peak cooling load for the entire building is approximately 10.5 MW, which is met by a series of four water-cooled chillers at basement level. Each incorporates two variable-speed compressors with the aim of maximising performance and efficiency. The BMS (Building Management System) controls the sequencing of the chillers and their associated primary circulation pumps, depending on the varying cooling load in the building. Heat rejection is accommodated at podium roof level, where two banks of cooling towers are carefully integrated into the raking podium roof structure and concealed by an architectural aluminium mesh overcladding.

As the primary business functions of the towers include financial transactions, brokering and dealing, resilience of the building services was a key consideration in the design. Each tower incorporates a data centre at level 2 and a series of sub-equipment rooms at each level of office accommodation. In terms of cooling and power supply, these facilities were designed to be highly resilient and able to continue operating in the event of primary system failure. This resilience is provided primarily by N+N system redundancy (ie each component has an independent back-up component) in terms of both cooling and electrical supply. Cooling is maintained by two wholly independent chilled water systems, while the electrical supply has both dedicated UPS (uninterruptable power supply) systems in each tower (in dedicated plant areas on level 1) and diesel generator back-up at ground floor level at the rear of the podium.

2.2 SKYGARDENS

A key architectural feature of the towers is the introduction of skygardens on the southern elevations of both towers (Fig 5).

Figure 5: Axonometric view of tower showing typical office floor layout at skygarden level

These are three- and four-storey open-air spaces that are formed by the removal of a section of the floor plates over a number of levels to create dramatic outward-facing environments.

The skygardens are separated from one another by several floors. The perimeter steel frame wraps around the skygardens to support the modular Mashrabiya devices. This creates a shaded external environment that allows employees to step into an external environment along the height of the towers. See Figure 6.

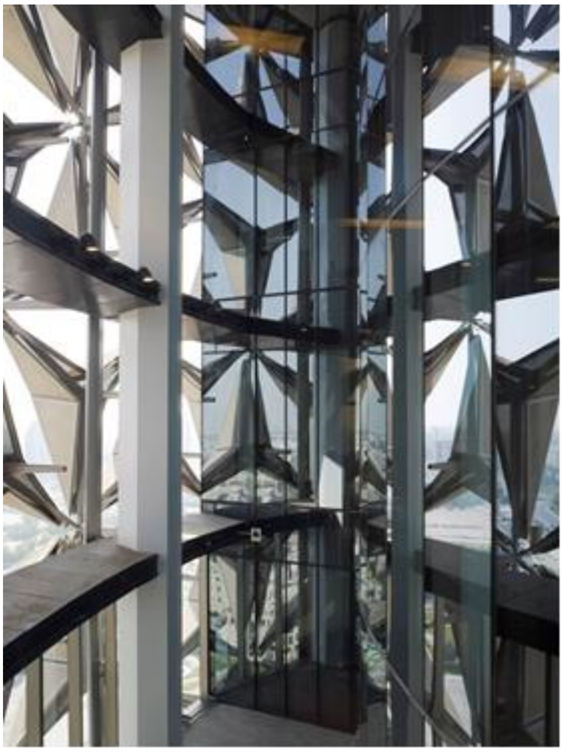

Figure 6: Completed skygarden from within office space.

3 TOWER FACADES – THE MASHRABIYA

The climate in Abu Dhabi is classified as subtropical desert, having maximum temperatures of around 46˚C and very high solar radiation levels year-round (Fig 7).

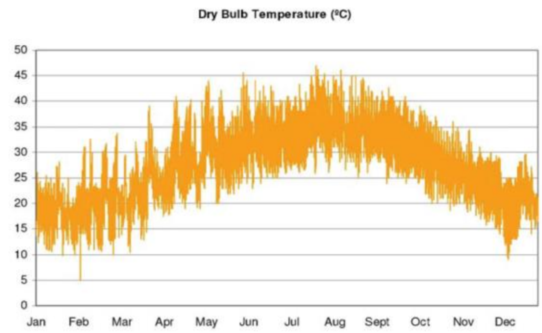

Figure 7: Average diurnal temperature range in Abu Dhabi

Most recent high-rise buildings in the Middle East use highly glazed façades with dark, reflective, or body-tinted glass. This type of solution limits solar gain, but significantly reduces natural daylighting and general internal comfort. Frequent use of internal blinds is normally needed to control glare effects and this inevitably increases the lighting energy consumption, defeating the purpose of a transparent building.

The design aspiration was to achieve a highly glazed building, allowing spectaular views from the inside whilst providing the best possible levels of internal visual and thermal comfort. The design approach sought was to adopt a more transparent glass than typically used for similar glazed buildings in the region, as this would result in key benefits including enhanced daylighting within the building, reduced use of artificial lights and associated energy saving.

The key difficulty was keeping the sun out - reducing the energy use associated with providing internal comfort was perhaps the biggest single challenge faced by the design team. The solution was the innovative Mashrabiya shading devices which wrap the Al Bahr towers. In fact, the Mashrabiya became a key architectural theme in the towers' design.

The design team undertook extensive solar and thermal analysis of the effect of this unique active shading system on select areas of the towers at various times through the year to identify the required extent of the shading device and its regime of opening and closing (Fig 8). This helped derive the precise portion of the North facing facade where shading is not required.

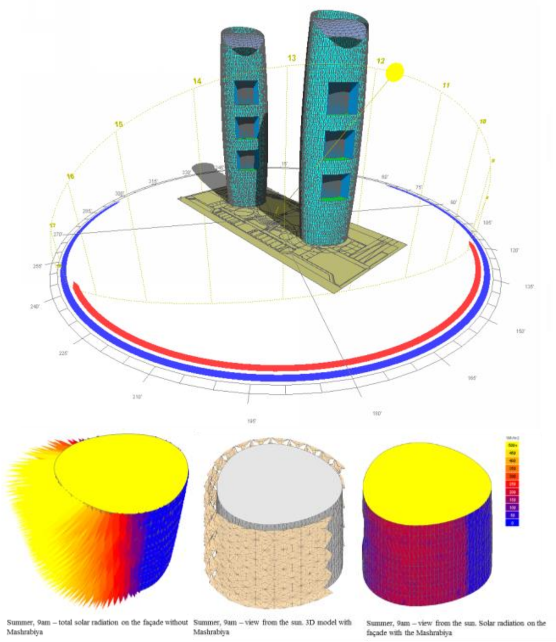

Figure 8: Solar exposure analysis

As built, the Mashrabiya clads the towers on their east, south and west façades, significantly reducing solar gain to the internal accommodation and permitting the use of floor-to-ceiling clear glazing. Different options were investigated to select the most appropriate fabric for the shading system, and PTFE-coated glassfibre mesh was identified as the most durable and best- performing solution.

In total, each tower has 1049 Mashrabiya panels, with each weighing about 600 kg (1.5 tonnes with supporting steel brackets). Arup built on knowledge gained in other projects with movable elements, and worked with the architect to conceive schematic parameters for these elements and their detailed performance specifications.

Various conceptual arrangements were assessed early in the design, including connecting all shading elements to one another and into the superstructure, but this led to conflicting behaviours between the Mashrabiya and the internal support structure. A more straightforward strategy was thus sought, in which each Mashrabiya was conceived as a unitised system cantilevering 2.8 m from the primary structure. The supporting arms allow connection to the ends of six adjoining Mashrabiyas, and each shading device has different releases at each of three supporting nodes.

The shape of the building in plan and elevation led to 22 different variations in the Mashrabiya geometries, which in itself created a technical challenge for managing their manufacture and assembly. No precedents of moveable shading systems on this scale were available and most of the design team's efforts focused on making sure that this unique and unconventional shading system was able to protect the buildings from solar radiation whilst operating reliably in an aggressive environment.

A series of prototype tests on a fully functional 1-to-1 scale shading panel were therefore carried out, including wind tunnel tests and accelerated tests in a climatic chamber. More than 30,000 opening-closing cycles were simulated at different temperature conditions (carying from 24 °C to 30 °C) and at different levels of relative humidity, whilst applying sand and salt water on all the critical joints. This step was essential to de-risk the design process and prove the required durability life of actuators, bearings and mechanisms. A full-scale mock up was subsequently erected on one of the towers, while the curtain wall was being installed, to allow the Mashrabiya mechanism to be tested in situ (Figs 9-11).

The result is a responsive and dynamic skin, able to react differently according to the sun's orientation and to adapt to varying external conditions throughout the year. As a result, the building's appearance is always changing, reflecting natural daily and seasonal rhythms. By detailed assessment of the combined shading and glass performances, a correct balance between solar control and light penetration has been achieved. The type of glass selected has a clear appearance with high visible light transmittance, enhancing the daylighting and the view through, while the external shading panels help reduce the solar radiation significantly — and only where and when needed. As a result, the Mashrabiya are designed to reduce the towers' carbon emissions by 20 percent.

Figure 9: Mock-up Mashrabiya in situ

Figure 10: Mock-up Mashrabiya in situ

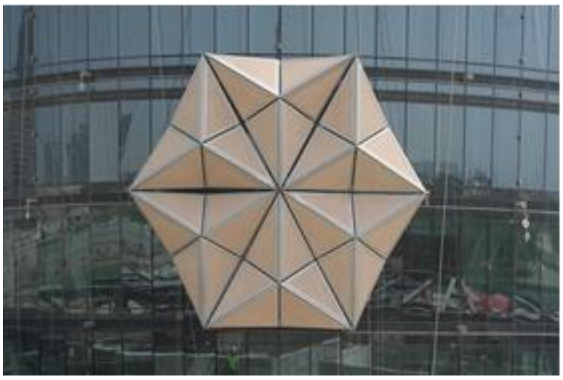

Figure 11: Mock-up Mashrabiya in situ

The Mashrabiya elements are grouped in sectors and operate by sun tracking software that controls the opening and closing sequence according to the sun's position. If necessary, the system can be overridden to control individual panels from a desk in the BMS control room. The control system is linked to an anemometer at the top of the building which will automatically prevent operation of the shading, and will retract the units if the wind speed exceeds the peak operating threshold. A similar approach, using solar radiation sensors, is used to trigger the opening of the Mashrabiya panels in prolonged overcast conditions.

The principle for access and maintenance of the Mashrabiya and curtain wall is via a BMU (Building Maintenance Unit) basket running externally within the cavity between the two skins. The baskets are supported by cranes on top of the central cores.

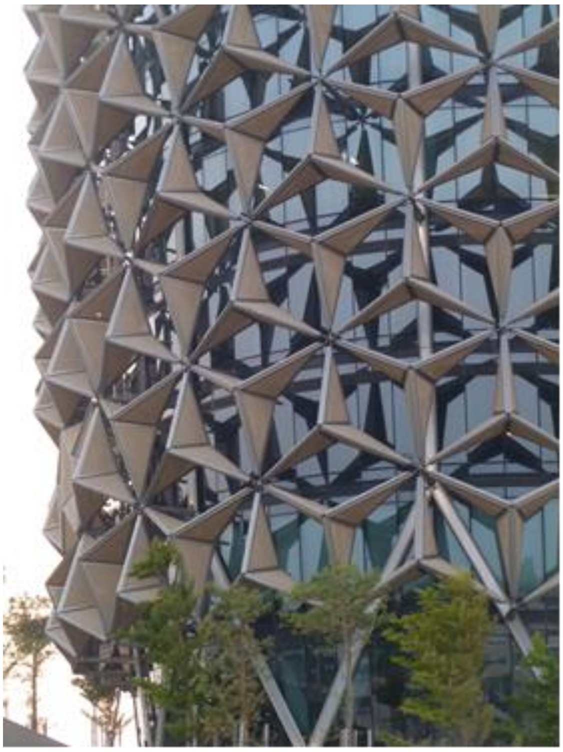

Figure 12: View of lower levels of south east tower

The curtain wall behind the shading is a standard unitised system shaped around the Mashrabiya brackets and developed to accommodate variable building geometries. The design and overall shape of the building were optimised to improve the panel repetitions, limiting rectangularity deviation and any warping. This helped to significantly reduce the system's complexity and ultimately the costs.

The vision area within the tower floor plates consists of floor to ceiling high double glazed units, with laminated inner and monolithic outer panes, both heat-strengthened. The heavily shaded nature of the towers having reduced gains due to solar radiation, entails that conductive gains from temperature difference is a determining factor. Particular attention was therefore paid to enhance the thermal performance by specifying Argon filled double glazed units and introducing thermal breaks where the brackets supporting the Mashrabiya penetrate the thermal line.

The building physics analyses carried out were crucial to define the correct balance between solar control and light transmission performances of the glazing and shading components, and the effect of the combined systems. A clear glass with a high performance coating has been selected, achieving a g-value (solar control) of 0.26 and a light transmission of 44%. Both values are significantly higher than any other similar building in the Middle East.

Figure 13: Mashrabiya in open configuration – view from inside office

4 THE CROWN

The crown was the subject of a separate solar and thermal analysis, so as to optimise the Mashrabiya extension at this level, and verify where the external shading system would be required, to provide an efficient cooling strategy. A 3-D model of the tower was carried out for the solar analyses. A simplified section of the top part of the tower was derived for a first solar exposure review, while a more detailed model was used for the sun path analysis.

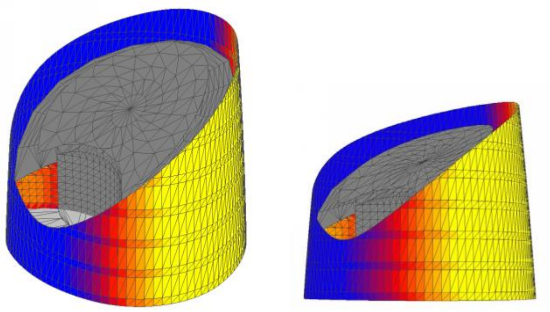

Figure 14: Total summer radiation in summer conditions at 9am

The solar exposure study (Figs 14,15) suggested that at the top of the tower, the Mashrabiya system should follow the configuration already conceived for its lower portions. However, due to the architectural desire not to extend the Mashrabiya to the very top of the crown and due to the shading system's distance from the façade, additional design measures were required to ensure that solar gains through the façade within the height of the crown were reduced below the target limit.

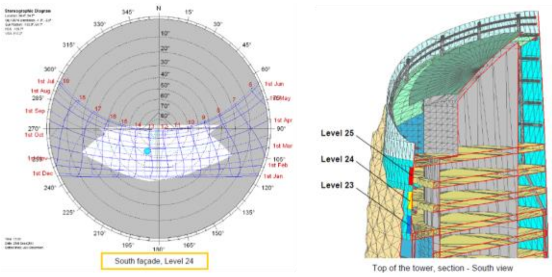

Figure 15: Shadow mask used to prove effectiveness of Mashrabiyas at the top of the crown to assess whether additional measures are required

The glass performance in this area was improved by applying additional fritting with a variable pattern according to the level of solar control required. This reduced the g-value and contains the solar gains (Fig 16).

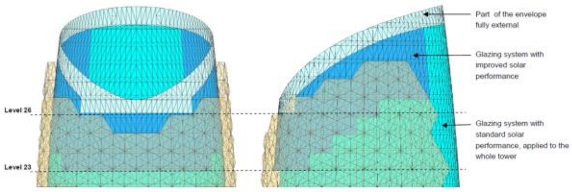

Figure 16: Modified shading system

Use of photovoltaic panels was considered on the roof surfaces of either tower. However, the presence of the two BMU cranes on either roof limited the area available. Furthermore, given water scarcity in the UAE, considerable energy is consumed for the desalination process to produce water to clean the PV when compared to the energy actually produced by the panels. Another determining factor was the potential deposition of airborne dust on outdoor photovoltaic modules. This could decrease the transmittance of solar cell glazing and cause a significant degradation of solar conversion efficiency of PV modules. The above reasons and the relatively low electricity prices in the UAE made the use of photovoltaic panels unfeasible.

5 PROJECT SUSTAINABLE CREDENTIALS

The project is being assessed under the US Green Building Council's Leadership in Energy and Environmental Design (LEED) tool. LEED considers areas such as energy efficiency, land use, water consumption, occupant comfort and materials specification. Comprehensive and flexible, LEED is a green building tool that addresses the entire building lifecycle, recognizing best-in-class building strategies. The Architect acted as the LEED administrator for the project during design, collating evidence from the rest of the team from an early stage to determine the target rating. Once on site, the contractor took over this responsibility. The final predicted rating is LEED Silver.

6 CRITIQUE ON THE APPLICABILITY OF THE SYSTEM TO THE MEDITERRANEAN REGION

The climate of the Mediterranean region is a type of subtropical climate, with high solar radiation levels. The maximum temperatures experienced are lower than those in the UAE.

The adaptable envelope conceived for the Al Bahr Towers could be applicable in principle to similar building projects in the Mediterranean region. A key parameter for the successful implementation of the Mashrabiya system on the Al Bahr Towers was the awareness by all the parties involved, including the client body and investors, of the inherent risks in implementing such a large-scale novel entity in the buildings and the collective endeavour to mitigate the risks at all stages of the project to transform the idea into a reality.

The additional tests required to mitigate the risk in adopting the system invariably had an upfront cost premium. Thus, there needs to be an understanding and financial commitment by funding entities to commit to these necessary procedures. The additional upfront costs (mostly incurred by additional tests) need to be weighed against the energy savings of the building in opereation – especially in Europe where energy costs are considerably higher than the Middle East.

Photovoltaic panels were deemed unfeasible on the Al Bahr Towers, resulting in pay back periods in excess of the life expenctancy of the panels themselves. However, this may not be the case in the southern Mediterranean region, where the energy performance of an analogous buiding would be enhanced by the introduction of photovoltaic panels.

7 CONCLUDING REMARKS

The Al Bahr towers are now a notable landmark in Abu Dhabi's financial district. Their adaptable skins, the Mashrabiya, form a key feature of the project, responding to the external environment, considerably reducing heat gain, and enhancing sustainability credentials.

The project won the 2012 Council for Tall Buildings & Urban Habitat's (CTBUH) Innovation Award, and was listed amongst the "Innovative 20" tall buildings that "challenge the typology of tall buildings in the 21st Century". It also featured in the November 2012 *Time* as one of the "25 best inventions of the year". It recently also won the 2013 Society of Facade Engineering Awards and the 2013 Middle East Architect Awards for best overall building and best commercial building.

Figure 17: View of completed towers

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Project credits

Client: *Abu Dhabi Investment Council, UAE*
Architect: *Aedas, London*
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Façade A&M: *Reef, London.*
Architect and Engineer of record: *Diar Consult, Abu Dhabi, United Arab Emirates.*
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