Integrating intelligent glass facades into sustainable buildings: cases from Abu Dhabi, UAE

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Abstract

Recent developments in the United Arab Emirates (UAE) have had consequences on the urban environment. Minimizing the impact of urban development on the natural environment and the trend to improve the ecological performance of buildings are the main concerns of sustainable and low energy building practices in Abu Dhabi. These ideologies have been acknowledged by international architectural firms to designing and constructing new projects that are energy efficient, environmentally friendly, and architecturally remarkable. Despite the fact that the UAE is one of the hottest countries in the Gulf region, the use of glazed façades in modern buildings has gained increasing popularity because of the better views, pleasant indoor environment, and the building’s prestige. These design approaches usually come with an increased operational cost due to the higher solar gain.

This paper investigates the increasing interest in integrating intelligent glass façades into sustainable buildings in the UAE in order to increase energy efficiency by improving thermal comfort and reducing cooling loads; improve occupants’ performance and comfort; and save the environment by minimizing the negative environmental impact. The study investigates typical glazed façade buildings exposed to the UAE environment, to understand the effect of the building skin on the energy demands in a hot climate. To reduce energy uses in buildings, advanced systems, including Double Skin Façade strategies have been tested and integrated into a high performance building. These strategies are to be developed, based on an individual funded research project carried out by the author, and the experience of previous researchers and building users.

Keywords: Abu Dhabi, energy efficiency, intelligent glass façade, sustainability.
1 Introduction

Despite the fact that Abu Dhabi is one of the hottest cities in the Gulf region, the use of glazed facades in modern buildings has gained increasing popularity. These design approaches usually come with an increased operational cost. It is important, therefore, to turn the principles of sustainable development into practice by increasing energy efficiency in buildings. Building engineers and architects should understand the behaviour of buildings they design if environmental performance and comfort are to be maximized. There are various approaches to increasing energy efficiency in buildings. These approaches take into consideration the total environmental and economical impact, energy sources, the performance of building material, design and construction, and operation and maintenance. The building façade is an important concept for energy efficiency. All components of the building façade need to work together to regulate the indoor environment. It is considered a selective pathway for a building to work with the climate, responding to heating, cooling, ventilation, and natural lighting needs. It must balance requirements for ventilation and daylight while providing thermal protection appropriate to the climatic condition [1]. Architects and building engineers should integrate the design of building façades with other design aspects including material selection, daylight, heating, ventilation, and air-conditioning.

The study examines the performance of building façades in the UAE environment in response to energy saving strategies. Intelligent dynamic systems, including Double Skin Façades (DSF) have been integrated into a high performance building in Abu Dhabi to reduce energy consumption and cooling load by reducing the overall heat transfer coefficient “U-value” and shading coefficient. To achieve the aim of the study, the following objectives have been highlighted: to investigate the role of glazed building façades that provide energy efficiency in buildings; to reduce cooling loads by enhancing thermal comfort and identifying the optimal parameters for building façades; and to reduce building operating costs by minimizing cooling energy use and enhancing daylighting. In this context, various issues including urban transformation patterns of Abu Dhabi; the sustainable development of Masdar city; and the performance of intelligent glass façade are to be considered.

2 Abu Dhabi and its urban development

Abu Dhabi is one of the seven emirates of the UAE. It is the largest emirate by area (about 85% of the total area), and the second largest by population after Dubai with about 1.2 million people. It is located in the oil-rich and strategic Persian Gulf region, bordered by Saudi Arabia, Oman, and Dubai. As far as oil production and reserves are concerned, Abu Dhabi is the first among other Emirates forming the UAE, it owns about 11% of the total world reserves [2]. Adopting a free market economy policy, the Emirate is a business centre for international firms. Abu Dhabi is characterized by a hot and humid climate with an average temperature of 40°C (in summer) and 28°C (in winter).
The Emirate of Abu Dhabi is divided into three major regions: Abu Dhabi City, the federal capital of the UAE; the Eastern Region; and the Western Region. Moreover, there are a number of important islands within the emirate including Das, Mubarraz, Dalma, Sir Bani Yas, Abu Al-Abyadh, and Saadiyat.

Abu Dhabi has become one of the most modern cities not only in the Gulf region but also in the world. The city started its urbanization process in the late 18th century when the Bani Yas Tribe first settled it in 1761, and the economy was centred on camel herding, date oases, fishing and pearl diving. The fast urban development that followed the discovery of oil in 1958, and the 1971 UAE federation completely changed the character of the city from a traditional architectural pattern to a modern style. Three issues motivate this transformation pattern: a) Abu Dhabi is an international trading centre; b) the dramatic nature of the city development; and c) the emerging status of the city as an urban region.

Architectural ideologies in Abu Dhabi have moved from a traditional vernacular pattern to a modern style. The traditional fabric style, as shown in figure 1, reflects the climatic condition, the cultures and customs of the residents, and the locally available building materials. High-density buildings, narrow shaded alleys, courtyard houses and wind-towers characterize this pattern. The modern approach, which was established during the second half of the 20th century, was concerned with highly specialized building techniques. The building industry and urban fabric had been strongly affected by two factors. First: the importing of building materials and the establishment of foreign factories in the city. Second: planning organization was based mainly on occidental codes and dominated by foreign professionals [3]. This modern style is highly recognized within the newly developed areas of Abu Dhabi. A number of enormous mega-projects have been constructed, including Marina Mall; Abu Dhabi Investment Authority Tower; and Emirates Palace Hotel and Conference Centre. Other large projects are now under construction, including Al-Raha Beach; Abu Dhabi World Trade Centre; Saadiyat Island Development Project, and Masdar City Development Project.

Figure 1: Traditional architectural fabric of UAE.
Saadiyat Island, with its area of 27 km², represents one of the most significant development projects in the history of Abu Dhabi. The island, which has 30 km of water frontage and boasts many natural eco-features including mangrove forests, is being developed as a strategic international tourism destination for about 150,000 residents. Saadiyat Island project, which will be completed in 2018, comprises seven individual districts (figure 2). They include a range of museums and cultural centres (Sheikh Zayed National Museum designed by Norman Foster, Louvre Abu Dhabi designed by Jean Novel, Guggenheim Abu Dhabi designed by Frank Gehry, and Performing Art Centre); hotels and resorts (nine 5 star hotels along 9 km of sea-front), civic and leisure facilities, and sea-front apartments and luxury houses [4]. The island will be linked to Abu Dhabi mainland via light rail system and a 10 km long highway with a bridge [5].

Figure 2: Saadiyat Island development project, Abu Dhabi [5].

The trend of urban development, which is rapidly experienced in Abu Dhabi, has negative impacts on the environmental aspects including high consumption levels of non-renewable recourses, and a high level of air pollution. Minimizing this impact on the natural environment and the efforts to improve the ecological performance of any project are the main concerns of sustainable building development during and after construction period [6]. In UAE, buildings consume more than 45% of total energy use; 25% of total water consumption; 70% of total electricity consumption, and 40% of total carbon dioxide emissions [7]. Abu Dhabi has been listed as one of the highest per capita fossil fuel consumers and carbon dioxide generators. Meanwhile, it has been listed as the top in consumer of energy per capita. Despite that fact, the environmental impact of buildings is often underestimated in most of the new urban developments, while the costs of building green are overestimated. Therefore, minimizing the impact of urban development on the natural environment and the trend to improve the ecological performance of buildings are the main concerns of the sustainable building practices in Abu Dhabi. These ideologies have been acknowledged by international architectural firms designing and constructing...
new projects that are energy efficient, environmental friendly, and architecturally remarkable. Architects like Foster and Partners already incorporated ecological and sustainable approaches in their designs. Masdar City, which is considered a unique project to maintain the new vision of Abu Dhabi 2030 master plan, is a significant development regarding sustainable practices that aim to reduce energy consumption, reduce waste and pollutions, and create a manifesto for sustainable life.

3 Toward sustainability: Masdar City

The concept of sustainability states that there is a need to improve the living conditions of the present generations without compromising the ability of future generations to meet their needs. Sustainable development refers to a socio-ecological process characterized by the fulfilment of human needs while maintaining the quality of the natural environment [8]. Sustainable development could be achieved by architects, engineers, designers, town planners, and manufacturers of building products working cooperatively to produce green buildings that are designed, built, renovated, operated, or reused in an ecological and resource efficient manner. Sustainable design, which refers to “green design”, “eco-design”, or “design for environment” reduces the use of non-renewable resources, and minimize environmental impact. Green Building or Green Architecture is an approach to architectural design that emphasizes the place of buildings within both local ecosystems and the global environment. Green building is the practice of increasing energy efficiency, while reducing building impact on human health and the environment through better design, construction, operation and maintenance [9]. Effective green buildings require careful attention to the full life cycle impact of resources. Building materials, one of the key issues, should be "green" and obtained from local sources. Low impact building materials should be used wherever feasible [9]. Reducing energy loads is another issue for green architecture. It is important to orient the building to take advantage of cooling breezes in a hot climate, and sunlight in a cold climate. To minimize the energy loads, passive solar design can be effective. Masonry building materials with high thermal mass are efficient for retaining the cool temperatures of night throughout the day. Moreover, buildings are often designed to capture cool winds. Many of these valuable passive strategies are employed in the traditional architecture of Abu Dhabi, as well as in new development plan of Masdar City. Passive solar design helps conserve valuable fossil fuel resources and reduces greenhouse gases that contribute to global warming.

The most important step in the passive cooling process is to develop an energy efficient building envelope to minimize heat gains and to catch cooling breezes. Depending on the climatic condition, passive solar design of the building envelope might comprise the following concerns: orienting more windows to the north; incorporating adequate shading devices that prevent solar radiation; incorporating thermally massive building materials; providing suitable insulation; using high performance glazing that reduces heat gain and admits natural light. Landscape and outdoor spaces also play an important role in
passive cooling strategies. Vegetation, water ponds and fountains are efficient elements in the cooling techniques [10]. In Abu Dhabi's hot climate, where cooling is a primary concern, much can be done to accelerate passive solar design and capture natural breezes to keep buildings cool and comfortable. Combining proper ventilation, courtyards, wind-towers, shading devices, thermal mass, incorporating advanced glazing elements into more comprehensive intelligent façades and building systems can reduce energy loads.

Masdar City, with an estimated cost of US$22 billion, was initiated in 2006 as the World's first carbon-free eco-city. It is being constructed 17 km away from the centre of Abu Dhabi, and targeted to a 2016 completion date. Designed by the famous architect, Norman Foster, Masdar city is planned to be the first city where carbon emissions are zero, waste is converted to energy, desalinated water production reduced by 75%, and 80% of water will be recycled and powered by 100% renewable energy [11]. The city includes Masdar Institute of Technology, laboratories and research facilities, commercial spaces for energy related companies, and science museum. The city will host 50,000 people, in addition to 40,000 commuters. Masdar, as a car-free city, will be linked to the centre of Abu Dhabi by a new mass transit railway [11]. A personalized rapid transport system will be provided with a pedestrian-friendly environment. The city is designed to be self-sustaining; therefore, the surrounding land outside the city will contain photovoltaic and wind farms, research fields and plantations, desalination plant, water treatment plant, a recycling centre, and visitors’ parking.

The outstanding architectural concept of Masdar city was based on traditional planning ideologies, which are characterized by narrow shaded alleys, courtyards, and wind-towers; together with advanced technologies to create a unique green-community (figure 3). The city was designed in an ecological and resource-efficient manner. The combination of green design techniques will not only reduce energy consumption and environmental impact, but also reduce running costs, create more pleasant spaces, and improve occupants' health. To produce lower greenhouse gas emissions, a variety of renewable energies are considered within the city development [11]. These technologies include:

a) Solar Energy: the use of Photovoltaic technology, as a solar power system is planned to provide almost 50 percent of the electricity required and it will be integrated into building structures within the development.

b) Wind Power: large-scale wind farms with their turbines are proposed and will be connected to the city electric power transmission network.

c) Concentrating Solar Power: a field of mirrors and tracking systems is provided to focus a large area of sunlight onto a specific small beam. The concentrated light is used as a heat source for a conventional power station.

d) Geothermal Heat: a heating and/or cooling system that uses the earth’s ability to store heat in the ground or water thermal masses.

e) Waste-to-Energy: the process of creating energy in the form of electricity from the controlled combustion of municipal solid wastes.

Water management has also been planned in an environmental manner. A solar-powered desalination plant will be constructed to provide the city with a water supply. About 80 percent of the water used will be recycled and reused for
irrigation and other domestic uses. It is also planned to reduce the city’s waste to zero [11]. Biological waste will be used as fertilizer; municipal solid wastes will be utilized as an additional power source; and industrial wastes will be recycled.

![Figure 3: Architectural fabric of Masdar City [11].](image)

### 4 Intelligent façade performance

The intelligent glass façade system is known as a dynamic and flexible system that accommodates change in the environment and in occupant needs; using self-regulating thermal protection and solar control measures [12]. This could be achieved by the use of natural, renewable energy sources such as solar energy, airflow, and geothermal heat. The dynamic glass façade has ecological and economical significance since it reduces the global greenhouse effect by limiting carbon emissions; and reduces the investment and operational cost of building technology. In designing a dynamic glass façade, two strategies should be implemented: keeping heat losses low, and avoiding undesired heat gains through solar radiation. This could be achieved by the number of glazing skins incorporated in the design (single-skin façades and multiple-skin façades) and the use of solar control devices. To achieve a certain level of solar control, as pointed out by Compagno [12], a coating can be applied to glass such as infrared-reflecting coatings. This glazing can change solar and light transmittance dynamically to respond to occupants’ needs and building conditions. It is necessary to provide additional adjustable solar control devices; including exterior or interior solar devices, or integrated shading devices incorporated in the cavity between the glass panels in the case of single-skin façade or between the glazing skins in the case of DSF.

The use of DSF technique as an intelligent glass façade has gained increasing popularity in many part of the world. It introduces at least two primary glazing layers separated by a cavity space that provides greater thermal insulation. This could be integrated with solar control systems, light reductions systems, and ventilation systems. The construction of the DSF usually provides better solar protection that can reduce the effect of the external load and the cooling need. The additional layer of glazing can reduce the insulation by about 10 percent.
Further reduction could be achieved by placing shading devices in the cavity space [13]. Shading devices help in absorbing heat and liberating it within the cavity. The absorbed heat is transmitted to the surrounding air and adjoining surface by means of radiation and convection. The position of the shading devices plays a major role in the distribution of the heat gains. As pointed out by Oesterle et al. [13], the optimal location of the shading device is in the outer half of the cavity. The air-tightness of the DSF also contributes to the qualities of thermal insulation. The improved U-value of the DSF depends mainly on the ventilation level of the intermediate space and the direction of the façade. The ventilation systems for the cavity and the inner spaces play an important role in sound transmission. The acoustical insulation between rooms depends on the differences in the ventilation strategy of the DSF (active, passive, and interactive types). Active types have internal mechanical ventilation with a high level of acoustical insulation. Passive types have natural ventilation of the cavity with a low level of acoustical insulation between rooms. Interactive types have natural ventilation with the aid of mechanical ventilator in the cavity. The degree of sound insulation provided by the DSF depends mainly on the size and position of the openings in the outer layer. Sound insulation can also be influenced by absorbent surfaces of the cavity [13].

5 Analytical study: the use of DSF

Despite its advantages in terms of energy efficiency, the use of the DSF system is limited in Abu Dhabi. The absolute construction cost of the DSF will always be higher than an SSF system. However advanced intelligent façades may allow tradeoffs with building systems including cooling and heating systems. To get a clear picture of the real economical incentives of using DSF, the author carried out an analytical study in 2006 as part of an individual funded research project on "Thermal performance of double skin façades in hot and arid climates". The methodology of the study was based on interviews with building designers and maintenance engineers; and simulation of single glazed façades and double skin façades. The study emphasized that the potential energy savings offered by the DSF strategy can overcome the high construction cost. Moreover, building performance and comfort can be maximized. A fully glazed double skin façade has been tested and analyzed. It incorporates an outer single glazed panel fastened to aluminum frames; inner double glazed operable windows with internal blinds, and a 40 cm cavity between the two skins. The cavity is divided horizontally and vertically along the construction axes and between the individual windows. The horizontal platforms are covered by laminated sheets, which act as horizontal shading devices. The comparison analysis of the performance of various glazing technologies with the performance of the used DFS showed that the solar heat gain coefficient for DSF systems with shading devices is between 0.09 and 0.30 W/m². As shown in table (1), this level of solar control can be achieved by a typical double glazing unit with reflective coatings, but at the cost of much higher thermal transmission, and lower natural light transmission. On the other hand, the use of clear double-glazing would result in a
solar heat gain coefficient much higher than a DSF and hence a higher cooling load. The U-value of the used DSF was found to be in the range of 0.9 – 1.4 W/m². It has also been concluded that this type of DSF has an acoustical insulation that is far better than that of a conventional double glazing single-skin façade. The difference can be as much as 10 dB. The airflow inside the cavity and the divisions between the outer and inner skins play an important role not only in thermal performance but also in sound control. As a result, the U-value is reduced, less energy is required, visual transmittance is high, and acoustical insulation is provided.

Table 1: Performance characteristics of different façade systems including DSF.

<table>
<thead>
<tr>
<th>Façade type</th>
<th>Solar Heat Gain Coefficient</th>
<th>Thermal transmission coefficient (U-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry wall</td>
<td>&lt;0.03</td>
<td>&lt;0.40</td>
</tr>
<tr>
<td>Double glazing single skin façade</td>
<td>0.30 – 0.40</td>
<td>1.1 – 1.5</td>
</tr>
<tr>
<td>Double glazing single skin with reflective coating</td>
<td>0.07 – 0.20</td>
<td>1.3 – 1.5</td>
</tr>
<tr>
<td>Double skin – vented with laminated shades within cavity space</td>
<td>0.09 – 0.30</td>
<td>0.9 – 1.4</td>
</tr>
</tbody>
</table>

The advantages of the DSF application depend mainly on the characteristics of the site, the function of the building, and the design of the façade and its integration with the inner spaces. In general, DSF can provide different functional approaches, including: a) sun protection and cooling load control, b) improving thermal comfort and providing daylight, c) enhancing natural ventilation schemes, d) reducing operating costs by optimizing the daylight-thermal trade-offs, and e) improving indoor environments and enhancing occupant health, comfort, and performance [14]. Generally, DSF strategy is a good approach to overcome the large energy conservation and comfort problems that are created by the use of excessive glazing areas. Economically, there is an additional cost for the construction of DSF compared with single skin façades. This additional cost has to be offset by the lower costs achieved through greater functional efficiency.

6 Conclusions

Modern developments in the Abu Dhabi have had consequences on the urban environment. Minimizing the impact of such development and the trend to improve the ecological performance of buildings are the main concerns of Abu Dhabi 2030 Vision toward sustainability. These ideologies have been acknowledged by international architectural firms, such as Norman Foster, to design and construct projects that are energy efficient, environmental friendly, and architecturally remarkable. Masdar city is a good example where carbon emissions are zero, waste is converted to energy, and 80% of water will be recycled and powered by 100% renewable energy. The use of natural ventilation, thermal mass, proper shading, careful siting and landscaping should be adopted
in sustainable buildings to reduce energy uses and increase occupants’ comfort. In addition to these strategies, the use of dynamic glass façade systems that accommodate change in the environment and in occupant needs is highly appreciated by architects and building engineers particularly in hot climates since it keeps heat losses low, and avoids undesired heat gains through solar radiation. The use of DSF techniques; integrated with solar control systems, light reductions systems, and ventilation systems, provides better solar protection that can reduce the effect of the external load and the cooling need, and improve the indoor environment.

References