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Glass Selection for High-Rise Residential Buildings in the United Arab Emirates based on Life Cycle Cost Analysis

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Abstract

The architect's decision to select a glass type for a high rise building has significant impact on both the initial and the running cost of a building. This is particularly the case with many of the new buildings that have a high window-to- wall ratio (WWR). While several competing factors impact the architect's decision, this study supports such a decision for buildings in the United Arab Emirates (UAE) by focusing on the relationship between the glass thermal characteristics and its cost. At this stage of the study, it uses a typical 30 story residential building with a WWR of 50% and a north-south orientation. An energy simulation modelling tool is used to provide data on the impact of different types of glass on the cooling load and hence the energy consumption. The cost and thermal properties of used glass types are those that actually exist in the market of the UAE. The study considers the different energy price structure in different parts of the country. Using both the simple payback period and the life cycle cost reduction techniques, optimal glass thermal properties are identified.

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Keywords: Glass selection; Energy effeciency; Energy modeling; High-rise residential; Life Cycle Cost analysis; United Arab Emirates.

1. Introduction

The United Arab Emirates has a population that grew at a rate of 3.1%, compared to a world population growth rate of 1.2% in 2012, and an economy that grew 4.9% compared to the world's growth rate of 2.8% in 2011 [1]. The growing economy is paralleled by an estimated growth rate of 4.5% in the construction industry for the year 2013, and an expected 5.3% growth rate between the years 2013 and 2021; Business Monitor International estimated the construction industry value in UAE to be approximately USD 41 billion in 2013 [2].

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This growth is also accompanied by an increase in electricity demand. Between the years 2010 and 2011, the demand for electricity grew by 12.5%, according to the Regulation & Supervision Bureau in Abu Dhabi [3]. The increase in demand could be partially related to the fact that previously rapid growth in the residential and commercial construction sector has not been matched by an equally rapid growth in local utilities sectors, which resulted in new buildings not having access to power and water, potentially for years, making them unusable [2].

It is worth mentioning that the electricity consumption per capita in UAE is 3.3 times that of the world's average per capita, and the primary energy use per capita is 4 times that of the world's per capita in the year 2010 [1]. Furthermore, the UAE's CO2 emissions per capita was 4.3 times that of the world's average per capita in 2009 [1]. Around 68% of the total electricity consumption is by the residential and commercial buildings sector, where cooling and air conditioning is responsible for about 70% of the peak electricity load in buildings during the summer [3]. The residential and commercial buildings, according to the Business International Monitor, has an estimated construction project value that is about 63% of the total construction sector value in 2013 [2].

Many of the above numbers can be attributed to the nature of buildings' design in the country. As Figure 1 illustrates, most recently built buildings, particularly high-rise, use curtain wall systems to enclose their high rising structures. The glazed portions of such buildings have got as high as 80% of the total building envelope area [4].

Clearly, in the sunny and hot Gulf region where the UAE is located, the design of the buildings' envelope has a major role in determining the cooling loads, and thus, the electricity consumption of the air conditioning systems. With a high glass ratio in the envelope, the performance of the selected glass is paramount in controlling such consumption. While it makes sense to minimize the cooling load by selecting glass with the best thermal performance, there are cost implications associated with this selection. Therefore, the consultant needs to identify the best selection considering the saving in energy cost versus the increase in glass cost. Such identification is certainly location dependent as it considers the environment in which the glass performs as well as the price of both the glass and the energy in the location. This is particularly important in a country like the UAE where the average subsidization rates for domestic fuels is estimated at 67.8% [6]

This paper documents a study that aims to support consultants in making the decision on glass selection. The paper starts with a review of relevant research work. It then explains the methodology used to conduct the study. The results are then presented and analyzed. This study is part of a series of studies that investigate different building design configurations to provide the best possible support for designers in deciding on glass selection in the UAE.

Figure 1. Sample of typical new high-rise buildings in the UAE

2. Related studies

A literature review on the subject revealed few studies with related objectives. In Hong Kong, a study conducted to assess the cost effectiveness of using high performing glass in residential high-rise buildings found that the use of double-glass with a low-e film is not economically viable; the study revealed that the application of expensive advanced glass cannot be justified merely by the achieved savings in cooling costs [7]. On the other hand, a life cycle cost analysis has been done by Ihm et al. for several glass types in South Korea [8]. Single glass, double glass, and triple glass assemblies were evaluated for their impact on cooling demand, taking into consideration the economic impact of each of the evaluated glass types. The research conducted deduced that using double low-e Argon-filled glass is the most cost effective type, and has the highest energy savings [8].

The two contrary recommendations reached by the findings of the two above mentioned studies on residential high-rise buildings attest to the importance of taking into account the various variables involved in the optimization of glass performance that are context specific. Such variables include the climate, the accessible glass technologies and their prices in a specific market, and the electricity prices.

Several research works targeted quantifying the energy savings in cooling loads through improving the thermal characteristics of glass. Noh-Pat et al. examined the impact of using solar control film on double glazed units in hot climates while varying the distance between the two glass panes [9]. The results they found showed that using a solar control film reduced the SHGC to 0.17 compared to 0.77 for the glass that has no solar control film, which means a 55% reduction in the solar thermal heat gain.

Lee et al. studied various glass assemblies for five different climates in East Asia [10]. The study included Manila's climate that is categorized under ASHRAE Climate Zone 1, matching the UAE's climate zone. The study found that, in the hot climate of Manila, using triple glazed units with a U-value of 0.797 $W/m^2.K$ and a SHGC of 0.209 could reduce energy demand for cooling by about 20%. Another study, done by Bahaj et al., examined the potentials of several glass technologies when applied to curtain walled buildings in the Middle East; their case study was in Dubai [11]. The study revealed that using fixed Holographic Optical Elements, which is a glass technology, could reduce the heat gains through an envelope using external blinds by one-third, whereas using tracked Holographic Optical Elements could save as much as 55% of the heat gains; the use of Aerogel glass was found to achieve a savings of up to 7%, while Electrochromic glass showed savings as little as 5% in heat gains.

Nonetheless, none of the mentioned research works in the UAE has taken into account the cost effectiveness of improving the thermal characteristics of the glass assemblage in the light of the subsidized electricity prices in UAE. Thus, the aim of this research is to fill this gap.

3. Methodology

The objective of the study is to determine the optimal thermal characteristics of curtain wall glass used in high-rise residential buildings in the UAE. The studied thermal characteristics are the glass conductivity (U-Value) and the glass Solar Heat Gain Coefficient (SHGC). These are evaluated based on the change in the cooling load and consequently the saving in the energy bill.

The study uses a simulation software to estimate the change in the cooling load as a result of using different glass thermal characteristics. The subsequent change in electricity consumption is estimated considering a standard value of three for the Coefficient of Performance (COP). Both the price of electricity - as sold for residential purposes in the UAE - and the price of glass - as collected from UAE suppliers - are used to make a cost-benefit analysis using both the payback period and the life cycle cost techniques. Based on the results, the research recommends certain glass thermal characteristics for high-rise residential buildings in the UAE.

3.1 Simulation environment

The simulation software Integrated Environmental Solutions- Virtual Environment (IES-VE) is used in this research [12]. The simulation accounted for both external as well as internal sources of cooling load, including heat gains from the envelope, occupants, lighting, and appliances.

While the envelope constructions are kept unchanged except for the studied component, the curtain wall glass, several simulations are performed, each with a different combination of glass thermal characteristics. The annual cooling load is estimated for each case and converted to annual electricity consumption using the COP value of three for the mechanical system typically used in similar building typology, and in accordance with the baseline conditions as set in ASHRAE 90.1-2010 [13]. This conversion is used to predict the change in the electric bill value due to different curtain wall glass types.

The light transmission characteristic of the glass is not considered in the study. Consequently, the impact of this characteristic on the possible reduction of the cooling load from artificial light is ignored. The authors believe that this impact has no practical value at the moment. Switching light on and off in residential buildings is highly dependent on the user behavior.

3.2 Building characteristics

The studied building is a 30-storey residential building. This number of floors is considered the average floor number for high rise residential buildings in the UAE. Accordingly, the operational schedules defined for the simulations are typical of residential typology, and in accordance with ASHRAE 90.1-2010 [13]. The studied building has been located in the city of Dubai in UAE and the weather file of Dubai is used. This location and its weather data is a good representation for the coastal area of the UAE where the majority of the developments exist.

The building geometry is a rectangular layout with the dimensions of 30m X 30m, and a floor-to-floor height of 3.2m. Each floor is divided into eight apartments and the services of the building are placed at the core of the building with the dimensions of 5m X 12m. This configuration as shown in Figure 2 can closely represent the configurations for residential high rise buildings in the UAE.

For simplicity at this stage of the study, the window-to-wall ratio (WWR) for the four elevations is assumed to be 50%, and the orientation of the building is assumed to be along the North-South axis.

The thermal characteristics of the building constructions are specified to meet the set values in ASHRAE 90.1-2010 for UAE that is categorized under Climate Zone 1 according to ASHRAE climate zones. Table 1 summarizes the thermal characteristics of the envelope constructions. The U-Value and SHGC of the curtain wall glass as specified by ASHRAE 90.1-2010 is assumed to be the baseline for the glass performance; thus, the various glass types that are studied are compared to this baseline.

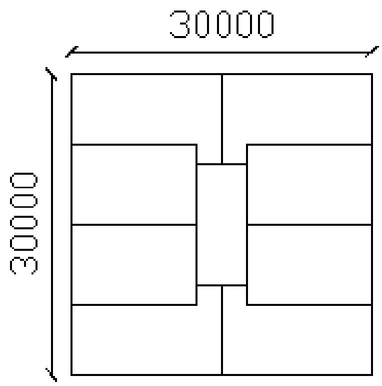

Figure 2. Typical layout of residential floor

Table 1. Thermal characteristics of the envelope constructions

Building Element		Thermal Characteristics	
		U-Value ($W/m^2.°K$)	SHGC
Opaque	Roof	0.37	NA
	Wall	0.53	
	Floor	1.99	
	Slab-on-Grade	1.63	
Transparent	Curtain Wall Glass	6.81	0.25

3.3 Studied glass types

The studied glass types are those typically used in glass curtain walls in high rise buildings in the UAE. Table 2 summarizes the types of glass studied and the thermal characteristics of each type and its price. For every glass type, a combination of the two parameters, U-Value and the SHGC, is used in the simulation as shown in table 2.

Table 2. Types of glass studied and their thermal characteristics and price (converted from UAE Dirhams)

Type No.	Composition	Thermal Characteristics		Price
		U-Value (W/m^2.°K)	SHGC	(\$/m^2)
a	Single glazing (6mm pane)	6.81	0.25	30
b	Double glazing (6mm pane + 12mm air gap + 6mm pane) and low-e Film	2.00	0.29	50
c		1.90	0.26	54
d		1.70		56
e			0.21	53
f		1.50	0.20	54
g		1.30		54
H		1.10	0.18	69
I			0.14	75

4. Results and discussion

The results of the simulations show that the reductions in annual cooling loads range between 5.6% and 9.7% compared to the baseline glass. The savings of each of the tested glass types are illustrated in Figure 3. For example, a reduction of 9.7% in annual cooling loads can be achieved using glass type **i** that has U-value of 1.10 W/m^2.K and SHGC of 0.14 as shown in table 2.

Glass types **c** and **d** perform almost typically, and so do the types **f** and **g**. This can be related to the fact that in both cases, the SHGC is fixed, while the U-values are different. Whereas the glass types **d** and **e**, and the types **h** and **i** have a relatively big difference in cooling load savings. In each of these cases, the U-values are similar while the SHGC are different. Thus, the results indicate that the impact of U-value on the annual load savings is smaller compared to that of the SHGC. This can be understood considering the small temperature difference between the set indoor temperature for air conditioning and the annual average of outdoor temperature (about 5°C in difference). Meanwhile, the annual average number of sunshine hours is very high (about 9.7 hours per day).

The change in glass thermal characteristics results in a change in the initial cost of glass. Figure 4 demonstrates the additional cost associated with each of the tested glass types based on a survey for glass prices in the UAE market. The table shows that an increase of 67% is associated with glass type **b**, and up to 150% with glass type **i** relative to the cost of the baseline glass. Therefore, a cost-benefit analysis is performed to identify the best glass type considering both the glass cost and its impact on energy consumption.

Two techniques are used for the cost-benefit analysis. The first is the simple payback period, which is an estimation of the number of years after which the additional initial cost of glass is returned due to energy bill savings. The second is the life cycle cost (LCC) whereby the total costs of purchasing, operating, maintaining, and disposal are calculated over the life time of the glass. The second technique is more comprehensive and effective when comparing alternatives. Nonetheless, the simple payback period is a supplementary measure that is consistent with the LCC analysis and provides an initial indicator for comparing alternatives [14].

To make the calculations for both techniques, the monthly cooling load (referred to as the Thermal kW·h) for every glass type is converted to electric energy consumption (referred to as the Electric kW·h) using the Coefficient of Performance (COP) of the mechanical system. For example, with the use of COP value of 3, a reduction of 100 thermal kW·h in cooling load results into a saving of 100/3 = 33.3 electric kW·h. The saving in electric consumption is then converted to a monetary value by multiplying it with the price of one kW·h of electricity.

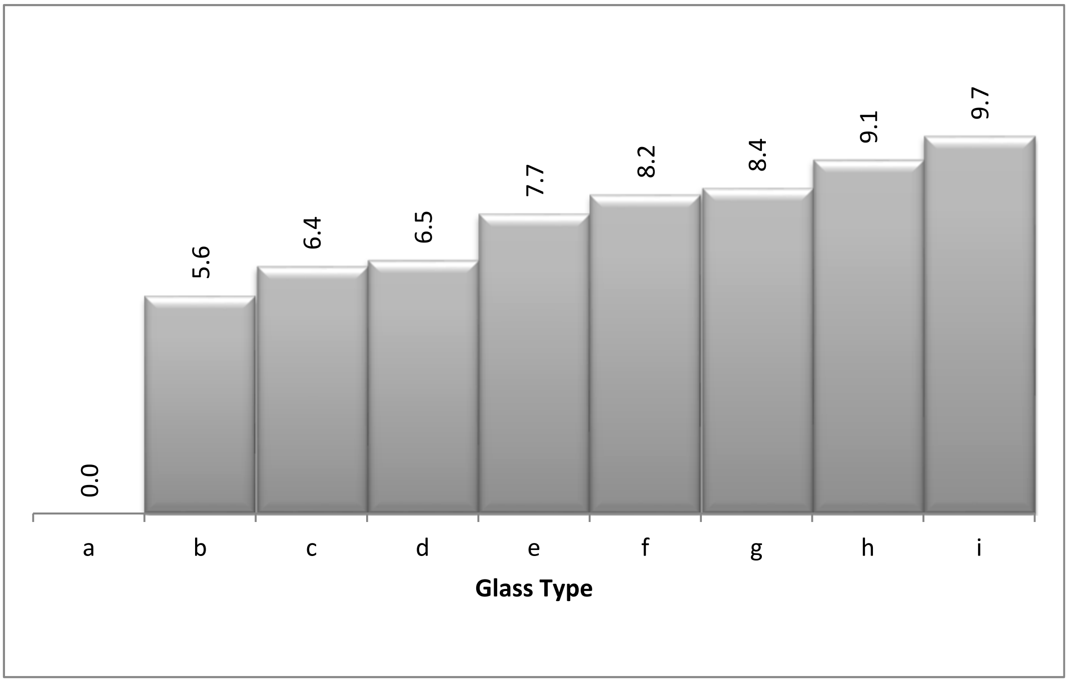

Figure 3. Percent annual savings in cooling load for the tested glass types

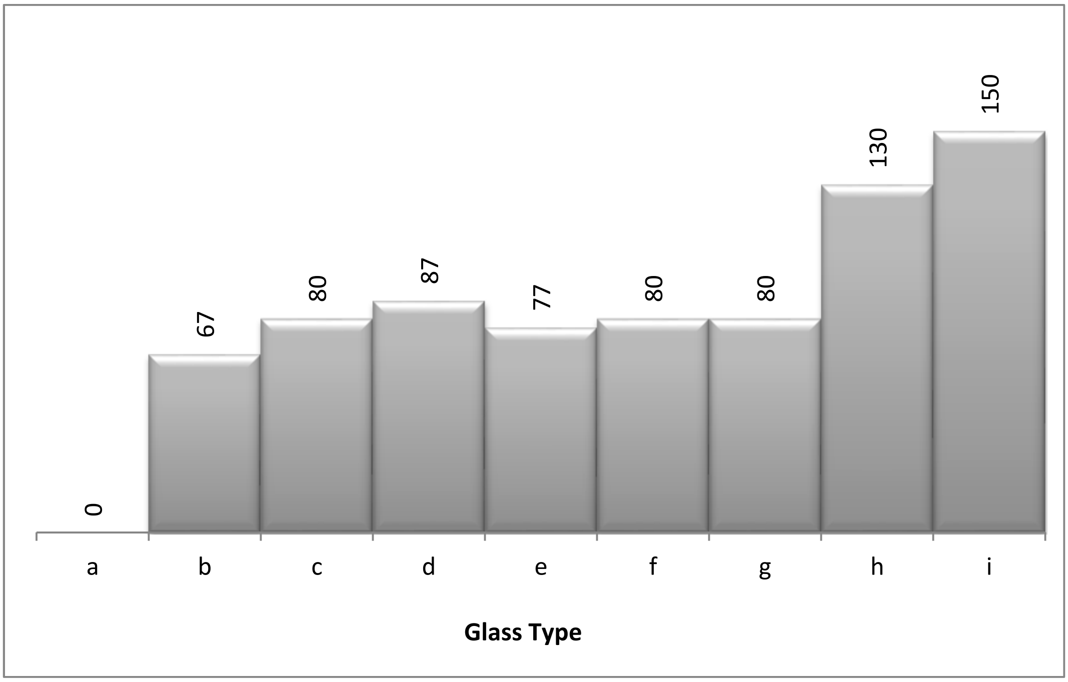

Figure 4. Percent change in glass cost

However, determining the price of electricity is a bit of a challenge as different emirates in the United Arab Emirates have different electricity price structures. The study covers the three largest emirates in the country. Abu Dhabi has a fixed price of $0.04 per kW.h [15]. Similarly, Sharjah has a fixed price of $0.08 per kW·h [16]. Dubai on the other hand has a slab tariff system where the price of electric kW·h is $0.06 for monthly consumption of less than 2000 kW·h, $0.08 for consumption between 2000 kW·h and 4000 kW·h, $0.09 for consumption between 4000 kW·h and 6000 kW·h, and $0.10 for consumption above 6000 kW·h per month [17].

To account for the slab tariff system of Dubai in this study, the monthly total building electricity consumption is estimated and then divided by the number of apartments in the 30 storey building. This calculation indicates the expected monthly price of electricity based on the Dubai slab tariff system. This monthly price is used to estimate the annual saving in electricity bill due to the impact of using different glass types.

Figure 5 shows the saving in energy consumption cost achieved by using different types of glass relative to using the baseline glass. It should be noted that due to the difference in Dubai's tariff structure, its energy bill savings are only slightly higher, in the range of 0.3% to 0.5%, compared to those of the fixed rates in Abu Dhabi and Sharjah. This is due to the fact that approximately 85% of annual cooling loads occur in the summer months (May to October) according to the simulations conducted, and are within similar tariff slabs for most of the glass types. Thus, the slab tariff structure affects only the remaining 15% of the cooling load; this means that, effectively, 85% of the annual cooling loads in Dubai are charged at a fixed rate of approximately $0.08 per kW·h.

Using the above data for glass cost and the calculated saving in energy consumption, a simple payback period calculation is performed for each glass type. As Figure 6 illustrates, glass types **e**, **f** and **g** have the lowest payback periods, with type **g** having the least, with 10.2 in Abu Dhabi , 4.9 in Dubai, and 5.1 years in Sharjah,. Glass type **i** turned out to have the highest payback period in the three emirates with periods of 16.5, 7.9, and 8.2 in Abu Dhabi, Dubai, and Sharjah, respectively.

A Life Cycle Cost (LCC) analysis is also carried out to take into account the several variables that come into play when selecting a glass type for a high-rise building. This analysis shows the cost of using a specific type of glass over its life time, including the capital cost, operational cost, maintenance cost, and salvation cost. However, in this study, the maintenance and salvation costs are neutralized, for they are similar for all glass types. The parameters that are used in calculating the LCC of each glass type are the total initial cost of glass, a glass life time of 25 years, a 2% annual increase in the electricity unit rate, and an 8% net present value discount rate. The lower the LCC value, the more cost effective the glass type is.

Figure 7 summarizes the reduction in LCC for each of the studied glass types compared to the LCC of the baseline glass type. Glass type **g** has the highest reduction in LCC with values of 2.1% in Abu Dhabi, 5.5% in Dubai, and 5.1% in Sharjah. Glass types **e** and **f** have the second highest reduction in LCC for the three emirates.

5. Conclusion

The study indicates that glass type **g** (U-Value of 1.30 W/m^2.°K and SHGC of 0.20) has one of the shortest payback periods and the lowest Life Cycle Cost in the three largest emirates in the UAE. Therefore, the study recommends using this glass type for high rise residential buildings with about a WWR of 50% and with an almost north-south orientation in the UAE. This recommendation reflects the specific climate condition of the UAE, the currently available glass types, the current price of these glass types in the country, and the current structure of energy prices. It is worth noting that the currently used codes in these emirates require the following minimum glass thermal characteristics when the WWR = 50%:

Abu Dhabi: U-Value = 1.9 W/m^2.°K and SHGC = 0.23 (Using prescriptive pathway values of Estidama) [18]. This is roughly glass type **e**.

Dubai: U-Value = 1.9 W/m^2.°K and SHGC = 0.28 [19]. This is roughly glass type **c**.

Sharjah: U-Value = 2.1 W/m^2.°K and SHGC = 0.30 [20]. This is roughly glass type **b**.

Further studies are being conducted by the researchers using the methodology established in this paper to investigate the impact of orientation, the windows-to-wall ratio, and the building typology on the recommended glass type.

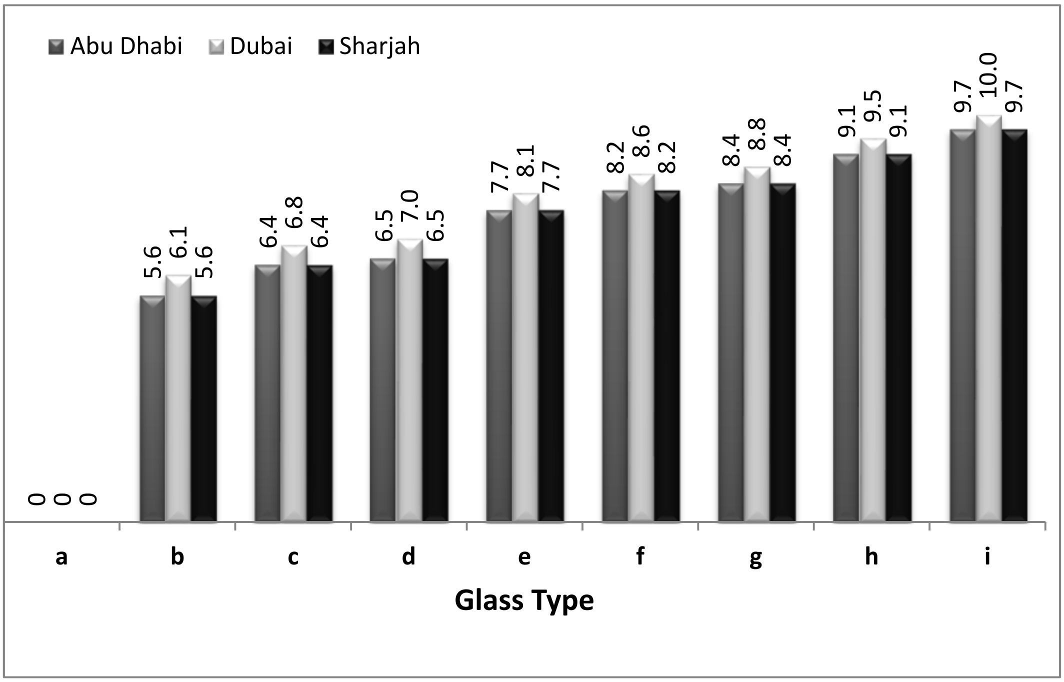

Figure 5. Percentage of saving in energy consumption cost

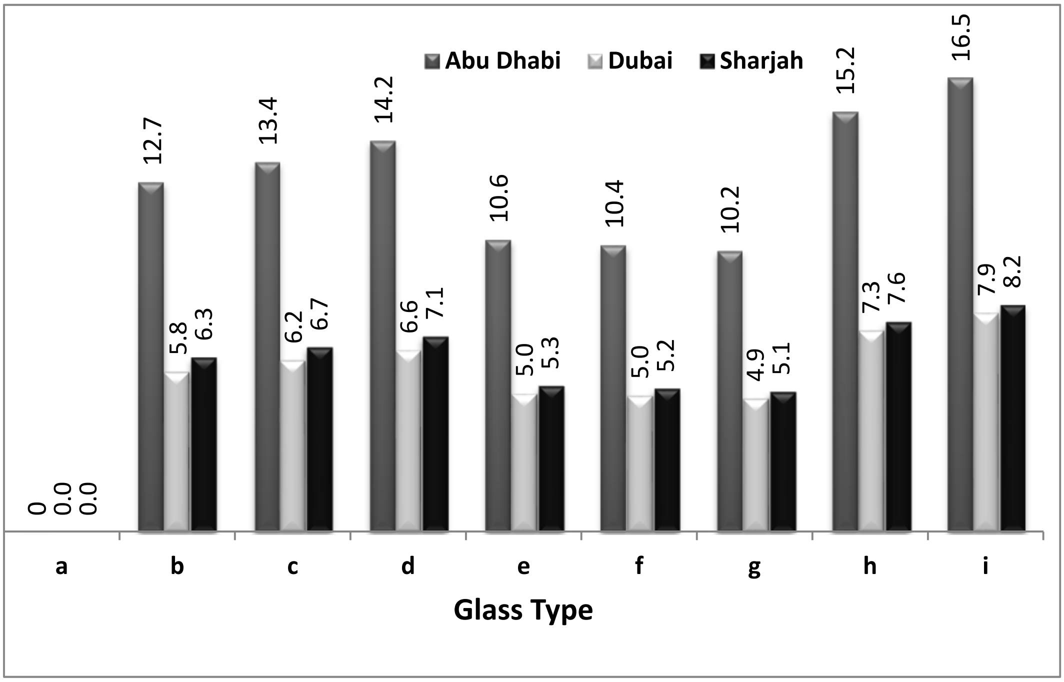

Figure 6. Results of calculating the Simple Payback Period

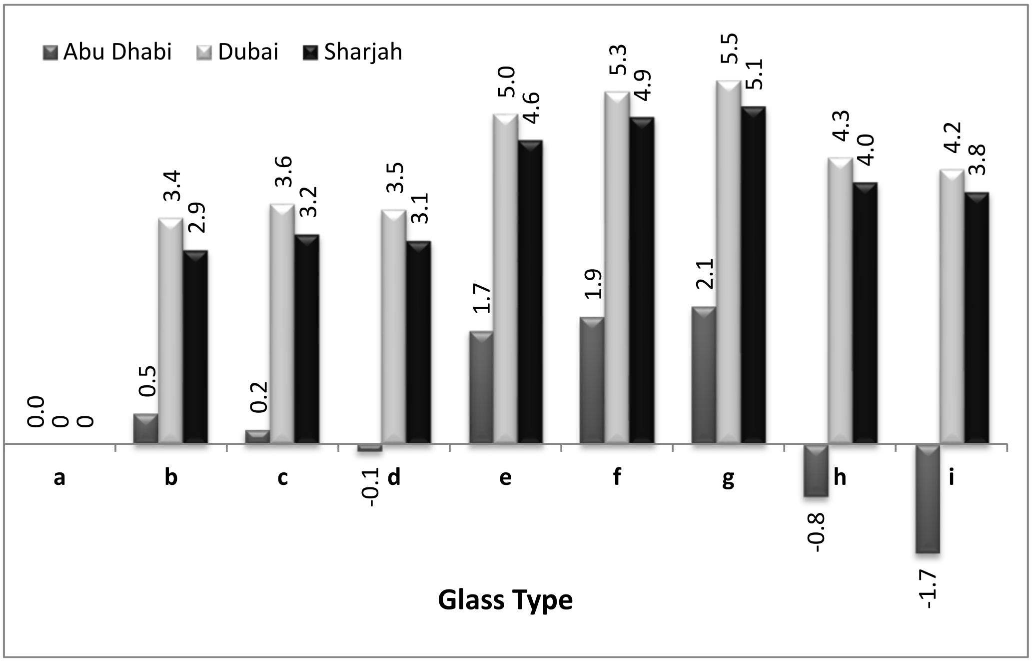

Figure 7. Reduction in Life Cycle Cost relative to that of the baseline glass

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