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Glass Selection for High-Rise Buildings in the United Arab Emirates Considering Orientation and Window-to-Wall Ratio

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Abstract

This paper is the continuation of a previous paper published by the authors. Both papers are for a study that considers the relationship among the glass thermal characteristics, its cost, and the price of electricity. This paper significantly expands the study by adding commercial buildings typology, considering two major building orientations and taking into account five different window-to-wall ratios. Energy prices and glass prices are also updated. Using the life cycle cost analysis technique, best thermal properties of glass are identified for different design scenarios. Considering that the results can differ with changes in input data, a sensitivity analysis is carried out to understand the impact of changing key input data. The results show that the building typology, orientation, and window-to-wall ratio are not the determining factors for identifying the best glass properties. They also show that the variation in price increase for different glass types is a critical factor in identifying the best glass properties.

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Keywords: Glass selection; Energy effeciency; Curtain wall; High-rise buildings; Life Cycle Cost analysis; United Arab Emirates.

1. Introduction

Tibi and Mokhtar have previously examined the selection of best glass type in high-rise residential typology with curtain walls for three emirates in the United Arab Emirates (UAE) [1]. They evaluated nine glass types with different U-values and different Solar Heat Gain Coefficient (SHGC) values for a building that has a window-to-wall ratio of 50% and North-South orientation to find the glass with optimal thermal characteristics. The Life Cycle

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Cost (LCC) technique was used to identify the glass type that minimizes the LCC of the curtain-wall glazing. The result showed that glass type with the U-value of 1.30 $W/m^2.°K$ and the SHGC of 0.20 was the best among all the glass types available in the country [1].

This paper documents the results of an expansion to the previous study using the same methodology [1]. However, in the expanded study, the authors added commercial typology to the residential one. In addition, two building orientations are evaluated for each typology, along with five different window-to-wall ratios ranging from 20% to 80%. The study also uses the new electricity price structure for the Emirate of Abu Dhabi and uses glass pricelists from more local suppliers. Because some of the used variables in the study can change overtime, a sensitivity analysis is also carried out to understand better the impact of changing these variables.

The paper starts with an updated review of related studies. It then explains the methodology used and how it is expanded in this study. It finally analyses the results, reaching to a conclusion.

2. Related Studies

Tibi and Mokhtar reviewed several studies related to the objectives of this work [1]. It is worth mentioning again the results of these reviews. They stated that "Among the studies related to this work is the one carried out in Hong Kong [2], where 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" [1]. Tibi and Mokhtar also refer to a study where "a life cycle cost analysis has been done by Ihm et al. [3] for several glass types in South Korea, where 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" [1]. Therefore, they found that "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" [1].

Several research works targeted quantifying the energy savings from reducing cooling loads through improving the thermal characteristics of glass. Penna, et al. examined passive energy efficiency measures for the climate of Milano, coupling an optimization algorithm with a simulation engine to run a multi-objective optimization analysis. Several design measures were examined for the optimal cost, energy performance and thermal comfort [4]. The researchers found that the optimal cost alternative reduced energy by 57%, but the thermal comfort conditions became worse unless low SHGC is used for glazing [4]. Stazi et al. used life cycle assessment, energy modeling and optimization analysis in an integrated approach to optimize the energy and environmental performance of complex building envelope, a solar wall, in central Italy [5]. The researchers found that the CO_2 emissions and energy demand throughout the life cycle of the building can be reduced by up to 55% using this type of envelope compared to the typical envelope design [5].

Tibi and Mokhtar also mentioned in the earlier paper that "Lee et al. studied various glass assemblies for five different climates in East Asia. 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%" [1]. Radhi et al. studied the use of multi-façade envelope to reduce the cooling load in multi-story fully glazed buildings in the UAE [6]. The authors found that savings of 17- 20% in cooling load can be realized using a low SHGC for the multi-façade glazing system [6].

3. Methodology

This study builds on and extends the previously established methodology by Tibi and Mokhtar [1]. The objective of the study is to determine the optimal thermal characteristics of curtain wall glass used in high-rise buildings in the three largest cities in the UAE. The study considers three variables for the building design: residential or commercial typology, each with two different orientations of North-South and 45° with North-South, and each with five different window-to-wall ratios of 20%, 40%, 50%, 60%, and 80%. Each combination of these three variables is considered a unique design scenario. As a result, twenty design scenarios were studied.

The studied thermal characteristics to define the best glass for each scenario are the thermal conductance (U-Value) and the Solar Heat Gain Coefficient (SHGC) of glass. Defining the best glass is based on the change in the cooling load and consequently the saving in the energy bill. The study uses simulation software to estimate the change in the cooling load as a result of using the different glass thermal characteristics. The subsequent change in electricity consumption is estimated considering a standard value of three for the Coefficient of Performance (COP).

The prices of electricity for both residential and commercial typologies are used or each of the studied emirates. Meanwhile, the prices of glass have been collected from several UAE suppliers and the average value for each glass type is used. Other data that can impact the cost such as sizing the cooling plant differently due to change in peak load are outside the focus of this study. An inflation rate of 2% is used to account for the expected increase in electricity price and glass prices over time. All this data along with a discount rate of 8% - which is the typical rate used in the real estate industry in UAE - are used to make a cost-benefit analysis using the life cycle cost techniques. Because these data are subject to unexpected changes, a sensitivity analysis is carried out to understand the effect of changing the electricity prices, the glass prices, the inflation rate, and the discount rate on selecting the optimal glass type for each design scenario. Based on the results, the study recommends certain glass thermal characteristics for each design scenario.

3.1. The Simulation Environment

The simulation software Integrated Environmental Solutions - Virtual Environment (IES-VE) is used in this expanded study as it was also used by the authors in the initial study [7]. The simulation accounted for both external as well as internal sources of cooling load; including heat gains from the envelope, occupants, lighting, and appliances. The envelope construction is kept unchanged except for the curtain wall glass type. For each design scenario, several simulations are performed, each with a different combination of glass thermal characteristics.

3.2. Building Characteristics

Two building typologies are used in this study. The first is a residential one where each residential floor is divided into eight spaces (Figure 1). The second is an office one with two offices in each floor (Figure 1). Both buildings have thirty floors, which is considered to be the average number of floors for high-rise building typologies in the UAE. The building geometry is a rectangular layout with the dimensions of 30 m x 30 m, and a floor-to-floor height of 3.2 m. The non-air conditioned plenum space is ignored in the office typology to simplify the modelling. The services of the building are placed at the core of the building with the dimensions of 5 m x 12 m. The window-to-wall ratio (WWR) for each of the four elevations is assumed to be the same. These configurations represent the typical ones for high-rise building typologies in the UAE. The operational schedules defined for the simulations are the typical ones for residential typology and for office typology in accordance with ASHRAE 90.1-2010 [8]. The studied building has been located in the city of Dubai and the weather file of Abu Dhabi airport is used. Selecting Dubai as the location was due to its middle location between the major three emirates that are considered in this study (Abu Dhabi, Dubai, and Sharjah). These are the Emirates where the majority of developments in the UAE occur. The weather file of Abu Dhabi Airport is used as it is the only available hourly weather data for the country.

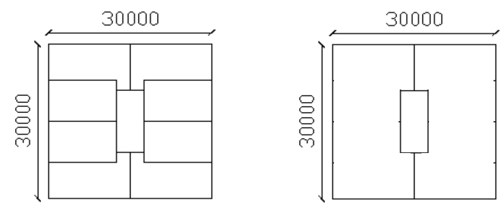

Figure 1. Typical floor layouts for residential (left) and office (right) typologies

3.3. Defining Baselines

In order to estimate saving in energy consumption due to different glass types, a baseline needs to be defined as a point of reference for such savings. Defining such a baseline must be in line with the objective of the study which is selecting the best thermal characteristics of the curtain wall glass for a building that is already designed. Because the building is already designed, its orientation and its WWR are already defined. Therefore, the study does not aim to define the best combination of building orientation and WWR in terms of energy saving. Rather, the best thermal characteristics of the glass. As such, there is a unique baseline for each particular combination of orientation and WWR (e.g. South-North with WWR = 40%). The study considers twenty building configurations that combine five WWR and two orientations for each of the two building typologies under study.

However, the thermal characteristics of the building construction materials remain the same for all the twenty different baselines. These thermal characteristics are those specified by ASHRAE 90.1-2010 for UAE (Climate Zone 1) [8]. The exception is for the curtain wall glass. These are changed as we study the impact of using different types of glass on energy savings. The calculation of energy saving is compared with the baseline case defined by ASHRAE 90.1-2010 where the glass U-Value is 6.81 $W/m^2.°K$ and the glass SHGC is 0.25.

3.4. Studied Glass Types

Similar to the initial study by Tibi and Mokhtar, the studied glass types are those typically used in glass curtain walls in high-rise buildings in the UAE. Table 1 summarizes the types of glass studied, including their thicknesses, thermal characteristics, and average prices. Glass prices are determined through calculating the average price for each type, using two pricelists obtained from the local market in the 4th quarter of 2014. For every glass type, a combination of the two parameters, U-Value and the SHGC, is used in the simulation as shown in table 1.

Table 1. Types of glass studied and their thermal characteristics and price (converted to US$ from UAE Dirhams)

<table>
<tr><th rowspan="2">Type No.</th><th rowspan="2">Composition</th><th colspan="2">Thermal Characteristics</th><th rowspan="2">Average Price ($/m²)</th></tr>
<tr><th>U-Value (W/m².°K)</th><th>SHGC</th></tr>
<tr><td>a</td><td>Single glazing (6mm pane)</td><td>6.81</td><td>0.25</td><td>45</td></tr>
<tr><td>b</td><td rowspan="8">Double glazing
(6mm pane + 12mm air gap + 6mm pane)
and low-e Film</td><td>2.00</td><td>0.29</td><td>49</td></tr>
<tr><td>c</td><td>1.90</td><td rowspan="2">0.26</td><td>51</td></tr>
<tr><td>d</td><td rowspan="2">1.70</td><td>55</td></tr>
<tr><td>e</td><td>0.21</td><td>63</td></tr>
<tr><td>f</td><td>1.50</td><td rowspan="2">0.20</td><td>70</td></tr>
<tr><td>g</td><td>1.30</td><td>77</td></tr>
<tr><td>h</td><td rowspan="2">1.10</td><td>0.18</td><td>90</td></tr>
<tr><td>i</td><td>0.14</td><td>88</td></tr>
</table>

4. Results and Discussion

4.1. Reduction in Cooling Load and Energy Bill

The simulations for both the residential and the office typology enabled the estimation of the savings in annual cooling loads, compared to the baseline glass, for each of the scenarios studied. Figure 2 and Figure 3 shows the results for the North-South orientation. The results are very close for the orientation of 45° with North-South. The difference between the two orientations is in the order of 0.1% for each scenario. This is understandable considering that the WWR is assumed the same for each of the four sides of the modeled building. Also, there are no shading devices that can make much of a difference in solar gain with different orientation.

As expected, the results show that the lower the glass U-value and SHGC, the more the reductions in cooling loads for each WWR studied. For example, in the case of WWR 20% in a residential typology, glass type **i** reduces the cooling load by 1.6% more than glass type **b** (both percent reductions are in comparison to glass type **a**). Also as expected, with the increase in WWR, the percent reductions in cooling loads also increase with the improved glass performance. For example, when comparing glass type **i** to glass type **b**, the percent reductions in the cooling load for the WWR 20% is 1.6% for residential typology and 1.8% for the office typology. Meanwhile, for the WWR 80%, the percent reductions in the cooling load is 5.3% for the residential typology and 7.2% for the office typology.

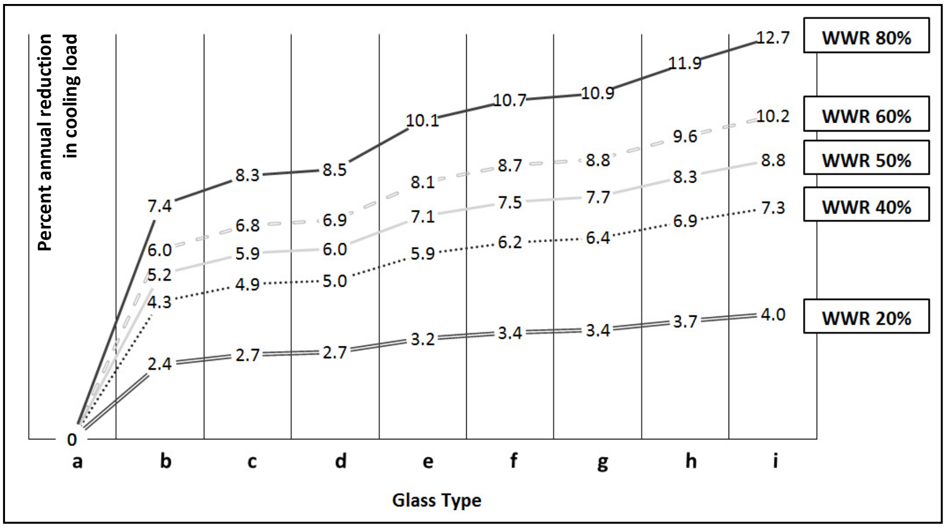

Figure 2. Percent annual reduction in residential typology cooling load for the tested glass types and WWRs along North-South axis

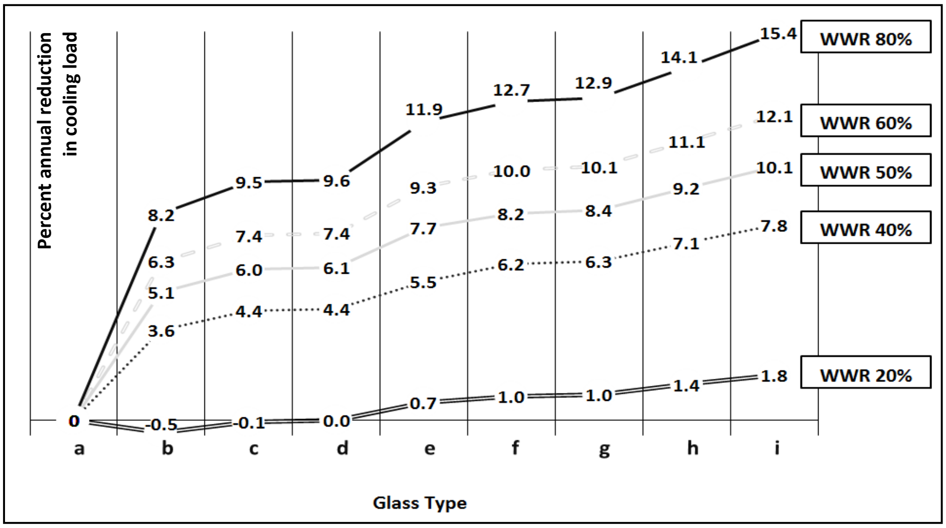

Figure 3. Percent annual reduction in commercial typology cooling load for the tested glass types and WWRs along North-South axis

Glass types **c** and **d** perform almost identically, 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. On the other hand, the glass types **d** and **e**, and the types **h** and **i** have a relatively big difference in the reduction in cooling load. In each of these cases, the U-values are similar while the SHGC are different. As concluded by Tibi and Mokhtar, "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 mean 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)" [1].

The range of differences in percentage saving for the residential typology is narrower than that of the commercial typology for each glass type. For example, Figure 2 shows that for glass type **e**, the saving in cooling load is 3.2% for WWR 20% and 10.1% for WWR 80% - a difference of 6.9% for the residential typology. Meanwhile, Figure 3 shows for glass type **e**, the saving in cooling load is 0.7% for WWR 20% and 11.9% for WWR 80% - a difference of 11.2% for the commercial typology. Considering that the external heat gains are the same for the two typologies, this can be attributed to the shorter operational schedule of the office typology compared to that of the residential typology. This difference in operating schedule impacts the internal heat gains. While the generated internal gains in the office typology are generally higher than that in the residential typology, these gains are generated over a period of 12 hours only in the office typology. However, for the residential typology, these gained are assumed to be continuously generated but with different occupancy densities throughout the day. Further, the cooling system is continuously active in the residential typology, but runs for only 12 hours in the office typology. These differences between the two typologies results in less internal heat gain and lower demand for cooling in the office typology. Consequently, the percentage impact of external heat gain in office typology is higher than that in residential typology. Therefore, for the same glass type, the lower the WWR, the less the possible reduction in cooling load for office typology than residential typology and vice versa.

Similarly, it is noted that the range of differences in percentage saving for residential typology is also narrower than that of commercial typology for each WWR. For example, Figure 2 shows for WWR 50%, the saving in cooling load is 8.8% for glass type **i** and 5.2% for glass type **b**; a difference of 3.6% for the residential typology. Meanwhile, Figure 3 shows for WWR 50%, the saving in cooling load is 10.1% for glass type **i** and 5.1% for glass type **b**; a difference of 5% for the commercial typology. As mentioned above, this is also attributed to the difference in internal heat gain between commercial and residential typologies.

4.2. Life Cycle Cost Analysis

The change in glass thermal characteristics results in a change in its initial cost. Glass prices in this study have been determined through calculating the average price for each type, using two pricelists obtained from the local market in the 4th quarter of 2014. Figure 4 summarizes the prices of the two sources and the average price that has been used.

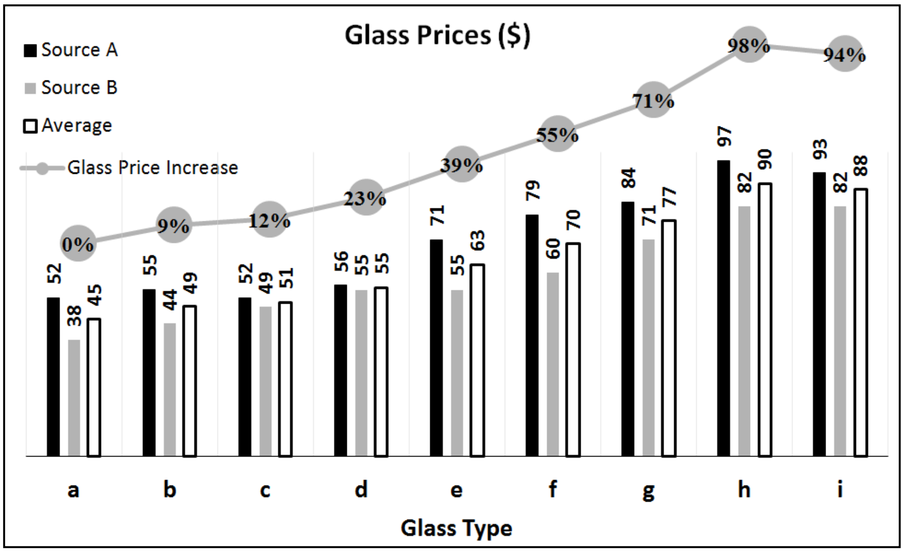

Figure 4. Glass prices for different glass types and percent change in the price

Following the methodology established by Tibi and Mokhtar, a Life Cycle Cost (LCC) analysis is carried out to identify the optimum glass type in each design scenario [1]. This 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, electricity consumption cost over the glass life time, a 2% inflation rate, and an 8% discount rate.

It must be noted that the electricity prices in Abu Dhabi have changed during the fourth quarter of 2014 [9]. This is part of the emirates strategy to rationalize the use of energy by reducing energy subsidies. A slab tariff system for several typologies including the residential typology is now in use, as opposed to the previous fixed rate of $0.04 per kW.h. Table 2 summarizes the prices of electric kW.h for the three studied emirates. To account for the slab tariff system, the approach developed by Tibi and Mokhtar is used [1]. In that approach, the monthly (for Dubai) or daily (for Abu Dhabi) total building electricity consumption, based on the simulation results, is divided by the number of apartments and office spaces in the 30 story building to estimate the amount of electricity used per flat and office. Based on this amount of kW.h, the monthly electricity bill for Dubai and daily electricity bill for Abu Dhabi are calculated using the applicable slab tariff price. This price - monthly for Dubai and daily for Abu Dhabi - is used to estimate the annual saving in electricity bill as a result of using different glass types. However, 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, the slab tariff structure affects only the remaining 15% of the cooling load. This means that, effectively, 85% of the annual cooling loads are charged at a fixed rate.

Table 2. Electric kW.h Unit Rates ($) used in the study

<table>
<tr><th>Typology</th><th>Abu Dhabi</th><th>Dubai</th><th>Sharjah</th></tr>
<tr><td>Residential</td><td>Slab tariff *
• 0 – 20 kW.h / day: 0.06
• > 20 kW.h / day: 0.09</td><td rowspan="2">Slab tariff
• 0 – 2000 kW.h / month: 0.06
• 2000 – 4000 kW.h / month: 0.08
• 4000 – 6000 kW.h / month: 0.09
• > 6000 kW.h / month: 0.10</td><td rowspan="2">• Fixed tariff: 0.09</td></tr>
<tr><td>Commercial</td><td>• Fixed tariff: 0.04</td></tr>
</table>

Table 3 outlines the percent reduction in LCC for each of the studied glass types compared to the LCC of the baseline glass type **a** in Abu Dhabi for the residential and commercial typologies. Glass type **c**, highlighted in dark grey, has the highest percent reduction in LCC values for all studied WWRs and orientations for both residential and commercial typologies. It is found as well that for both of the studied orientations with WWR 20% and in the case of the commercial typology, the lowest LCC reduction compared to the baseline glass type is negative. This means that the glass type **c** increases the LCC for these two design scenarios by 1.2%. This can be attributed to the low WWR in these scenarios, such that the cost of improving the thermal characteristics of the curtain wall glass is higher than the savings in electricity bill over the glass life time of 25 years.

Table 4 presents the percent reduction in LCC for the studied glass types compared to the LCC of the baseline glass type **a** for the residential and commercial typologies in Dubai. Glass type **c**, highlighted in dark grey, has the highest percent reduction in LCC values for all studied WWRs and orientations for both residential and commercial typologies. Yet, glass type **e**, also highlighted in dark grey, has the same percent reduction in LCC for the residential typology in Dubai. This is for all studied WWRs and orientations except the WWR 80% for the orientation along the North-South axis. However, the difference is very small. This outcome, which shows two different glass types with similar LCC reduction percentage, means that the electricity bill for each of the two scenarios counter balance the change in glass price, due to different thermal characteristics between types **c** and **e**, resulting in similar overall LCC reduction. The results for Sharjah show the same pattern as Abu Dhabi but with slightly different numbers.

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* These rates are for the expatriates, who constitute around 80% of the country's population [10]. The local citizens have subsidized rates.

Similar to the findings in Abu Dhabi and Sharjah, for both the orientations studied for the commercial typology with WWR 20%, the LCC percent reduction has a negative value. This means that glass type **c** increases the LCC for these two cases by 0.6%. As mentioned above, this can be attributed to the low WWR in these scenarios; nonetheless, the increase in case of Dubai is only half that in Abu Dhabi. The reason for this difference is the fact that the price of electric kW.h in Dubai is higher than that in Abu Dhabi, therefore, more savings are realized in Dubai making the investment in better glass performance more viable.

Table 3. Percent reduction in Life Cycle Cost for the cases studied in Abu Dhabi

Orientation	WWR	Typology	LCC % Reduction by Glass Type								
			a	b	c	d	e	f	g	h	i
0°	20%	Residential	0.0	2.1	2.4	2.2	2.3	2.1	1.9	1.5	1.9
		Commercial	0.0	-1.3	-1.2	-2.2	-3.2	-4.5	-6.0	-8.3	-7.6
	40%	Residential	0.0	3.8	4.2	3.9	4.1	3.8	3.3	2.7	3.3
		Commercial	0.0	1.5	1.6	0.0	-3.7	-3.8	-6.4	-10.3	-9.0
	50%	Residential	0.0	4.5	5.0	4.7	4.8	4.5	3.9	3.2	3.9
		Commercial	0.0	2.4	2.5	0.6	-1.3	-3.7	-6.8	-11.3	-9.7
	60%	Residential	0.0	5.2	5.7	5.3	5.5	5.2	4.4	3.6	4.5
		Commercial	0.0	3.0	3.2	1.0	-1.1	-3.8	-7.3	-12.3	-10.6
	80%	Residential	0.0	6.2	6.9	6.4	6.7	6.2	5.3	4.3	5.4
		Commercial	0.0	3.8	4.0	1.4	-1.1	-4.3	-8.4	-14.4	-12.2
45°	20%	Residential	0.0	2.1	2.4	2.2	2.3	2.2	1.9	1.6	1.9
		Commercial	0.0	-1.3	-1.2	-2.2	-3.2	-4.4	-6.0	-8.3	-7.5
	40%	Residential	0.0	3.8	4.3	4.0	4.1	3.9	3.3	2.8	3.4
		Commercial	0.0	1.6	1.7	0.0	-1.6	-3.7	-6.3	-10.2	-8.8
	50%	Residential	0.0	4.5	5.0	4.7	4.9	4.6	4.0	3.3	4.0
		Commercial	0.0	2.4	2.6	0.6	-1.2	-3.6	-6.7	-11.2	-9.6
	60%	Residential	0.0	5.2	5.8	5.3	5.6	5.2	4.5	3.7	4.5
		Commercial	0.0	3.1	3.3	1.1	-1.0	-3.7	-7.2	-12.2	-10.4
	80%	Residential	0.0	6.3	7.0	6.4	6.7	6.3	5.3	4.4	5.4
		Commercial	0.0	3.9	4.1	1.5	-1.0	-4.2	-8.3	-14.2	-12.1

Table 4. Percent reduction in Life Cycle Cost for the cases studied in Dubai

Orientation	WWR	Typology	LCC % Reduction by Glass Type								
			a	b	c	d	e	f	g	h	i
0°	20%	Residential	0.0	2.2	2.4	2.3	2.4	2.3	2.0	1.8	2.1
		Commercial	0.0	-0.9	-0.6	-1.1	-1.2	-1.7	-2.4	-3.3	-2.7
	40%	Residential	0.0	3.9	4.3	4.0	4.3	4.1	3.6	3.2	3.8
		Commercial	0.0	2.6	3.0	2.2	-0.2	1.2	-0.1	-1.6	-0.6
	50%	Residential	0.0	4.6	5.1	4.8	5.1	4.9	4.3	3.8	4.5
		Commercial	0.0	3.7	4.2	3.3	3.1	2.1	0.6	-1.2	0.0
	60%	Residential	0.0	5.2	5.8	5.5	5.8	5.5	4.9	4.3	5.1
		Commercial	0.0	4.6	5.2	4.1	3.9	2.8	1.1	-1.0	0.4
	80%	Residential	0.0	6.4	7.1	6.6	7.0	6.7	5.9	5.1	6.1
		Commercial	0.0	5.9	6.6	5.2	5.0	3.7	1.6	-1.0	0.8
45°	20%	Residential	0.0	2.2	2.4	2.3	2.4	2.3	2.1	1.8	2.1
		Commercial	0.0	-0.8	-0.6	-1.0	-1.1	-1.6	-2.3	-3.2	-2.6
	40%	Residential	0.0	3.9	4.3	4.1	4.3	4.1	3.7	3.2	3.8
		Commercial	0.0	2.6	3.1	2.3	2.1	1.3	0.0	-1.6	-0.5
	50%	Residential	0.0	4.6	5.1	4.8	5.1	4.9	4.4	3.8	4.5
		Commercial	0.0	3.8	4.3	3.3	3.2	2.2	0.7	-1.1	0.1
	60%	Residential	0.0	5.3	5.9	5.5	5.9	5.6	5.0	4.3	5.2
		Commercial	0.0	4.7	5.3	4.2	4.0	2.9	1.2	-0.9	0.5
	80%	Residential	0.0	6.4	7.1	6.6	7.1	6.8	6.0	5.2	6.2
		Commercial	0.0	6.0	6.7	5.3	5.1	3.8	1.7	-0.9	0.9

4.3. Sensitivity of Results to Input Data

It can be concluded based on the above tables that glass type **c** is the best to use in all the three Emirates for both residential and commercial typologies. However, this result is dependent on the data used to calculate the percentage reduction in LCC. This data are the inflation rate, the discount rate, the electricity prices, the glass prices, and the reduction in electric consumption due to lowering the cooling load. To check the sensitivity of each of the used data to the identified best glass, the percent reductions in the LCC is recalculated for each design scenario with an incremental 1% change in the value of each of these variables. The only exception is for the reduction in electric consumption because it is assumed to be fixed considering the assumptions made in the simulation process.

Table 5 shows the percentage change (in the value of each variable) at which the best glass is no longer type **c**. For example, in the residential typology in Abu Dhabi, if the inflation rate - which is used to account for expected increase in the prices of electricity over time - becomes 4% rather than the assumed 2%, then the best glass type is no longer type **c**. Similarly, if the discount rate - which is used to reflect the future value of money invested to buy the better glass - becomes 5% rather than the assumed 8%, then the best glass type is no longer type **c**. Also, the type **c** is longer the best glass type if Abu Dhabi suddenly increased electricity prices for residential buildings by 25% or more relative to the process shown on table 2. It is the case as well if glass prices suddenly increased by 470% or more relative to the prices shown in table 1.

The table shows that the identified best glass type is generally resilient to the individual changes in the value of these variables except for the residential typology in Dubai where a change in the best glass type occurs at a value very close to the one used in the model. The table also shows that residential typology is generally more sensitive to changes in these variables than commercial typology.

Table 5. Sensitivity Analysis

Parameter	Value Used in Model	Sensitivity Analysis – Best glass type changes at:					
		Abu Dhabi		Dubai		Sharjah	
		Residential	Commercial	Residential	Commercial	Residential	Commercial
Inflation Rate	2%	≥ 4%	≥ 14%	≥ 3%	≥ 8%	≥ 4%	≥ 9%
Discount Rate	8%	≤ 5%	≤ -4%	≤ 6%	≤ 2%	≤ 5%	≤ 1%
Sudden Increase in Electricity Price	See Table 2	≥ 25%	≥ 315%	≥ 7%	≥ 80%	≥ 25%	≥ 110%
Sudden Increase in Glass Price	See Table 1	≥ 470%	≥ 40	≥ 650%	≥ 270%	≥ 470%	≥ 280%

However, comparing the result of this study to the one conducted a year ago by Tibi and Mokhtar shows a change in the identified best glass type [1]. In the first study where only one scenario with one orientation and one WWR was studied, the result showed that the best glass type is **g** rather than **c** as identified in this study. This change occurs despite using the same inflation rate and discount rate in both studies. The structure of electricity prices in Abu Dhabi has indeed changed during this one year for residential buildings. A 50% increase is made for consumption up to 20 kW.h/day and a 225% increase is made for consumption above 20 kW.h/day. However, electricity prices for commercial buildings remained at the same price. Electricity price in Sharjah has also increased by 12.5%. According to the upper three rows of table 5, the best glass type should have remained the same from the last year study except for residential typology in Abu Dhabi. Therefore, the last row seems to be the critical one in identifying the best glass type.

However, table 5 shows that glass price has to suddenly change significantly for the result for the best glass to change. Such a large change did not occur. Hence, to understand the contradiction in the results of the two papers and the data in table 5, we need to understand the nature of glass prices in the UAE market. Within one year (2013 to 2014), the increase in prices for the various glass types in the UAE market varied significantly. For some glass types, the price increase was up to 30%, but for other types, the increase was only 2%. Such variation clearly cannot be attributed to inflation rates, especially that the inflation rate in the UAE was 2.2% in 2014 [11]. Rather, it could be due to factors such as a growing demand for some glass types more than others, change in solar films technology, supply chain costs, etc. This variation in price increase for different glass type resulted in identifying a different best glass type. The result is more sensitive to this factor more than any other factor used in the study.

5. Conclusion

The result of the study shows that glass type **c** (U-Value of 1.90 $W/m^2.°K$ and SHGC of 0.26) has the highest Life Cycle Cost percentage reduction in the three largest emirates in the UAE. This is applicable for high rise residential and commercial typologies regardless of their WWR and the orientations. This result is specific to the climate conditions in UAE, the geometric form of the building, the currently available glass types, the current prices of these glass types in the country, and the current electric energy prices. This leads to the conclusion that WWR, orientation, or typology does not have a significant impact on the LCC of curtain-walls' glass selection.

A sensitivity analysis to the financial data used to calculate LCC indicated that the result is generally resilient to changes in these data. However, a comparison between the result of this paper and an earlier paper by the author indicates that the variations in the increase of the price of different glass types do impact the result. This is an important conclusion that can be used by the UAE authorities when setting codes for glass thermal characteristics. Glass types with high thermal characteristics may appear to be too expensive to use at a point in time. However, requiring such a glass type by code will significantly increase the demand for it. While such increase in demand can initially increase the price of this glass, it should ultimately reduce its price relative to other glass types due to production and transportation in large quantities. This relative change in glass types can make the high performing glass financially feasible. More detailed study on this possibility is recommended.

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