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Selection of External Wall Material by LCC Technique for Ofice-cum-Commercial Building in the Eastern Province of Saudi Arabia

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Abstract: The building construction sector in the Kingdom of Saudi Arabia (KSA) is the largest and fastest in the GCC states. Building Envelope has a major role in deciding the cost and energy performance of a building. As far as KSA is concerned, application of life cycle costing (LCC) technique, which performs the cradle-to-grave assessment of a building, for selecting building materials and structures is rarely reported in the literature. The present study has focused on selecting external wall material based on life cycle cost (LCC), at the design stage. A typical office-cum-commercial high-rise building situated in Al-Khobar, Eastern Province of KSA, has been selected for the study. The LCC of the building was evaluated by employing 14 commercially available external wall materials, by considering a life span of 20 years. The building was modelled by using Autodesk REVIT (2015) and the energy consumption of the building was calculated by performing energy simulation by the ECOTECT (2011) software. The uncertainty and sensitivity analyses were performed by using Monte Carlo simulation technique, by employing Crystal Ball Software. The results indicate that the external wall material adopted for the building is not recommendable in terms of both initial cost and LCC. The best material options identified share common features such as 12.5mm inner layer of Gypsum Board, 150 mm Concrete Block, 70 mm Polystyrene or Polyurethane insulation layer and an outside layer of 12 mm cement plaster. These options offer 7% saving in LCC compared to the default option.

Keywords: External wall; Life cycle cost; Commercial building; Initial cost; energy consumption; Monte Carlo simulation.

1. Introduction

The building design process involves many scientific skills, and the structural, mechanical, electrical and construction systems of buildings require engineering expertise to achieve the required objectives[1]. Among various components of a building, the envelope plays a crucial role in deciding its overall cost and energy performance. The heat transfer through a building envelope constitutes about 40-45% of the total thermal load of the building, depending on the percentage of the glazed area and the infiltration rate[2]. Thus selecting thermally appropriate external wall materials for building construction is significantly decisive in reducing the energy consumption[3]. However, the selection of envelope material or configuration is often influenced by budget constraints, local availability and lack of technical information. Some materials that are attractive in terms of initial cost, can have adverse effects on quality, reliability and performance, during the life span of the building. Therefore, the need for a cradle-to-grave costing approach for the selection of external wall material is obvious.

A lot of approaches have been reported

for material selection for building construction applications. For instance, Ogunkah and Yang [4] employed Analytic Hierarchy Process (AHP) to identify the important factors affecting architects' decisions for selection of green vernacular building materials, during the design-decision making process. A multi-factorial analytical decision support toolkit was developed to assist architects assess their consequences in terms of whether or not the material option was likely to move towards sustainability objectives. In order to help decision-makers with the selection of the right materials, Castro-Lacouture et al. [5] proposed a mixed integer optimization model that incorporated design and budget constraints while maximizing the number of credits reached under the Leadership in Energy and Environmental Design (LEED) rating system. Akadiri et al. [6] proposed a building material selection model based on the fuzzy extended analytical hierarchy process (FEAHP) techniques, wherein the assessment criteria were identified based on sustainable triple bottom line (TBL) approach and the requirements of building stakeholders. A questionnaire survey directed to building experts was conducted to assess the relative importance of the criteria and aggregated them into six independent assessment factors. The FEAHP was used to prioritize and assign important weightings for the identified criteria.

The LCC approach for selection of building materials has also been a topic of research. Emmanuel [7] estimated the environmental suitability of five of the most commonly used wall materials (brick, cement masonry unit, cabook, rubble and wattle and daub). An "Environmental Suitability Index" was developed based on parameters such as embodied energy, life-cycle costs and re-usability. The possibility of using similar indices for other materials in Sri Lanka and elsewhere were also explored. In subsequent studies on Sri Lankan buildings, Abeysundara et al. [8][9][10] employed an approach for material selection based on the environmental, economic and social impacts in the life cycle perspective. The theoretical assumptions and the practical usefulness of the LCC approach in making environmentally responsible investment decisions were discussed by Gluch and Baumann [11]. In an attempt to re-engineer the Whole Life Cycle Costing (WLCC) process in the construction industry, Kirkham [12] developed a decision-support software application namely 'Logbook', which works simultaneously with a WLCC model to provide the designers of buildings with a repository of decision data (via the WLCC model), and a sequential, chronological record of the decisions made based on this data – from inception through to final design optimization. Morrissey and Horne [13] have presented an integrated thermal modeling, LCC approach for residential buildings in Australia. In a similar study, Menconi and Grohmann [14] developed a thermal simulation model integrated with LCC approach to identify the best choice of insulating material to retrofit the roofs of existing livestock buildings in Italy. By analyzing the entire life cycle, the best materials were glass wool, sheep wool and hemp fiber, while the polyurethane, despite having the best response in terms of temperature control, was at the last place because of its high primary energy input. Focusing on commercial buildings, Kneifel [15] estimated life-cycle energy savings, carbon emission reduction and cost-effectiveness of energy efficiency measures, and estimated the implications from a cost on energy-based carbon emissions. A total of 576 energy simulations were run for 12 prototypical buildings in 16 US cities, with 3 building designs for each building-location combination. The simulated energy consumption and building cost databases were used to determine the LCC effectiveness and carbon emissions of each design. Alshamrani [16] has proposed a framework for the selection of structure and envelope types for Canadian school buildings on the basis of sustainability standards and LCC.

The literature lacks in application of LCC for selection of external wall materials and configurations. The Kingdom of Saudi Arabia (KSA) is the leading country in the Gulf Corporation Council (GCC) region in terms of number and scale of construction projects, accounting for 43 % of the total construction projects in the region [17]. The building sector in KSA, particularly the commercial sector, has been growing rapidly over the past 20 years [18]. However, the building practices used are adopted from other countries with little consideration to local design requirements [19]. Withr espect to material selection, the building domain in KSA lacks a standard method that may help the decision-maker select the more-appropriate materials for the building to meet the design, budgetary and environmental requirements on a life-cycle perspective. As far as the business trend of buildings in KSA is concerned, most of the multi-story residential apartments are given for rent, wherein the tenants pay the electricity and water bills while some annual maintenance is done by the owners; hence the owners usually care only about the initial cost. However, in the case of commercial and office buildings, some are rented while many (including private and government buildings) are run solely by the owners. So, the LCC approach has prominence in situations where the owner becomes liable for the total operating cost of the building, which is the focus of the current study. A multi-story office-cum-commercial complex (fully operated by the owner) situated in Al-Khobar (Eastern Province, KSA) has been selected to study the effect of external wall material and configuration on the LCC of the building. The LCC was evaluated by employing 13 commercially available external wall configurations (with different materials), by considering a life span of 20 years. The energy consumption of the building was estimated by energy simulation by the ECOTECT (2011) program. The uncertainty and sensitivity analyses were performed by using Monte Carlo simulation technique.

2. Methodology

In the present study, a typical multistoried office-cum-commercial complex (under construction) situated in Al-Khobar, KSA, has been selected to explore the impact of external wall material and structure on the LCC of the building. The building specifications are summarized in Table 1. Including the default configuration, 14 external wall options commonly available in the local market have been chosen (as summarized in Table 2). In the LCC procedure, the major component of the operational cost is energy consumption cost. The building model (Figure 1) was built in Revit (version 2015) and then exported to the Ecotect (version 2011) simulation program for estimating the energy consumption. Ecotect is widely employed by researchers and professionals, and its capability as an energy simulation tool is well established [20]. The energy cost was estimated by using the tariff provided the Electricity and Cogeneration Regulatory Authority of Saudi Arabia, as shown in Table 3. The data for weather and location were chosen for Dhahran as generated by Ecotect. The overall procedure for the present LCC approach is illustrated in Figure 2, and Table 4 summarizes the details of each cost component and sources of data collection. The uncertainty and sensitivity analyses were performed by Monte Carlo simulations by using Crystal Ball software.

Table 1: The study building specifications

Item	Description /specification
Location	Al-Khobar, Saudi Arabia
Weather zone	Dhahran, Saudi Arabia (latitude N 26° 17' and longitude E 50° 12')
Number of floors, and shape	20 stories, commercial building, square shape
Total height	86 m
Size of each floor	30 m × 30 m
Gross floor area	18000 m²
Floor data	Ceramic tile 20 mm, cement 25 mm, sandstone 50 mm, reinforcement concrete 120 mm, concrete block 250 mm,
	Plaster 20 mm (U-value= 1.71W/m^{2}K)
Roof data	Ceramic tile 20 mm, cement 10 mm, sandstone 50 mm,
	Polystyrene foam 20 mm, asphalt 5 mm,
	Reinforcement concrete 150 mm, concrete block 200 mm,
	Plaster 10 mm (U-value= 0.33 W/m^{2}K)
Number of occupants	720 (maximum)
Lighting	20 W/m²
Type of lighting	Fluorescent
Equipment	7 W/m²
Infiltration rate	0.20 ACH
Set point temperature	21-26 °C
Windows	Double-glazed; U- value = 2.758 W/m^{2}K
Window to wall ratio	1:3

Table 2. The external wall options with specifications

	External wall Structure (Material Code*-Thickness in mm)					
	Inner Side	Layer 1	Layer 2	Layer 3	Layer 4	Outer Side
Option 1	GB-12.5	R-400	EP- 50			AC- 04
Option 2	GB-12.5	CB-150	AG-50	CB-100	AG-40	GM-40
Option 3	GB-12.5	CB-200				P-12
Option 4	GB-12.5	CB-150	PS-50	CB-100		P-12
Option 5	GB-12.5	CB-150	PU-50	CB-100		P-12
Option 6	GB-12.5	CB-150	PS-70	CB-100		P-12
Option 7	GB-12.5	CB-150	PU-70	CB-100		P-12
Option 8	GB-15	RW-100	AG-100			PC-175
Option 9	GB-12.5	CB-150	AG-50	CB-100	P-20	M-40
Option 10	GB-12.5	PU-75	CB-150	P-12.5		M-25
Option 11	GB-12.5	CB-150	AG-50			B-100
Option 12	GB-12.5	CB-200	P-12.5			M-25
Option 13	GB-12.5	CB-200	PS-50			AC-4
Option 14	GB-12.5	CB-200	RW-50			AC-4

AC	Aluminum cladding	CB	Concrete block	S	Stone
EP	Extruded polystyrene	PS	Polystyrene	M	Marble
GB	Gypsum board	PU	Polyurethane	B	Brick
GM	Granite marble (mech.)	PC	Precast concrete	P	Plaster
AG	Air gap	R	Reinforcement	RW	Rock wool

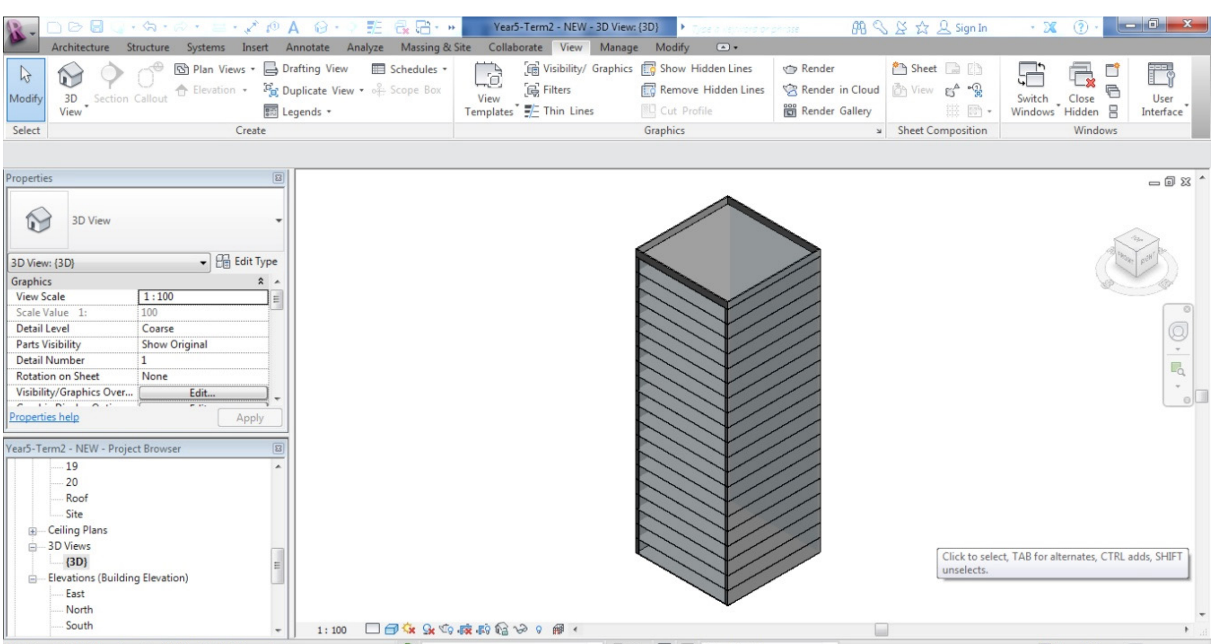

Figure 1: Study building model built in Revit

Table 3: Electricity Tariff for commercial buildings in Saudi Arabia (www.ecra.gov.sa)

Consumption Range (kWh/month)	Unit Cost (SAR/kWh)
1 - 4000	0.16
4001 - 8000	0.24
8001 and above	0.30

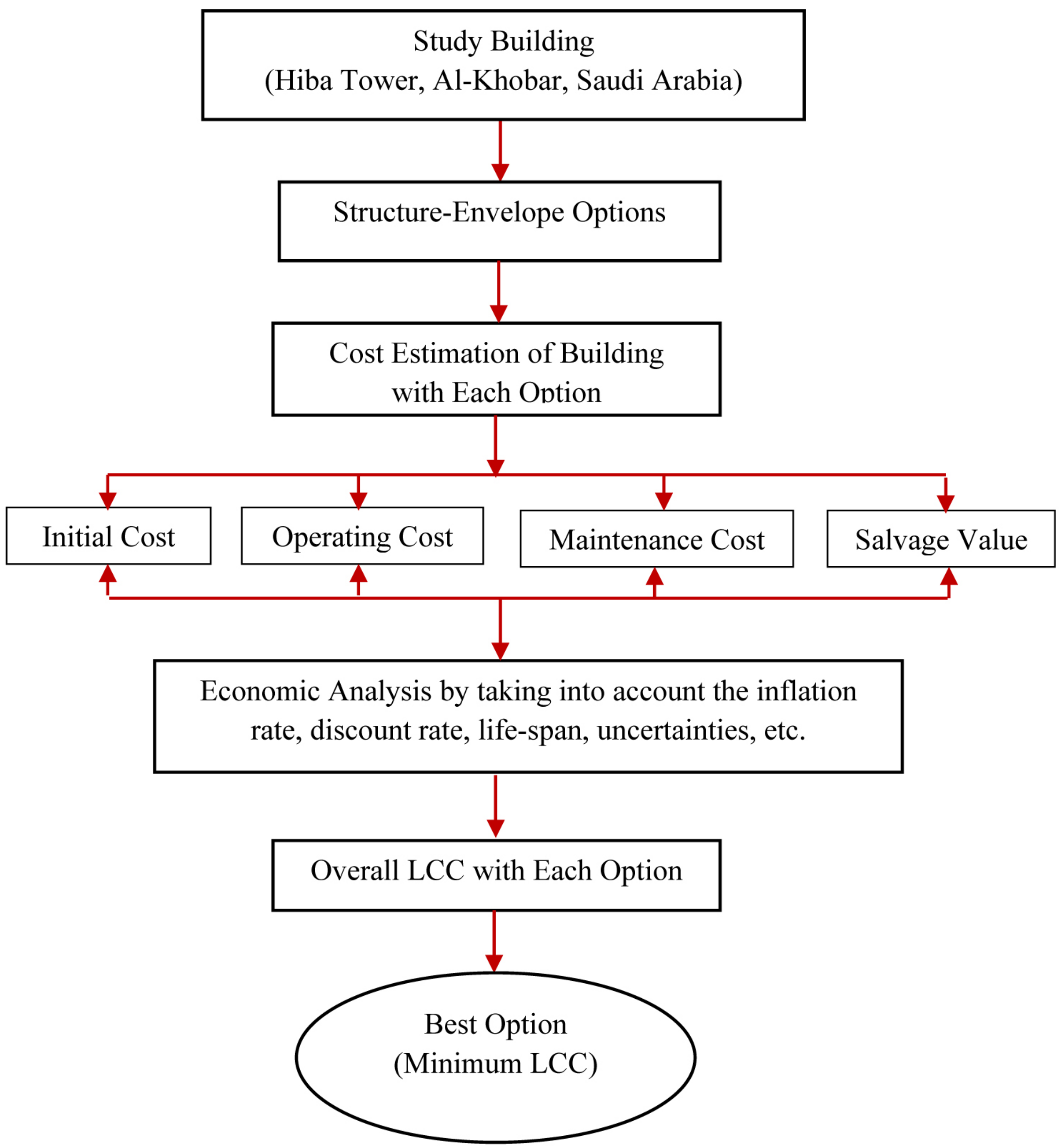

Figure 2: The present LCC model.

Table 4: Cost components and data sources.

Cost Component	Split-up		Data Source
Initial cost	Construction	Material	Construction contractor
		Labor	
		Equipment	
		Other related	
	Architectural or design fee		
	Contractor's profit		
Operating	Energy		Energy simulation
	Insurance		Owner
	Utilities		
Maintenance	Cleaning		Maintenance contractor
	Periodic repairs		
	Major repair/replacement		
Salvage value			Previous studies and survey on local factors

3. Results and Discussion

3.1 Annual Energy Consumption and Energy Cost

Figures 4 and 5 show the annual energy consumption and corresponding energy cost of the building with various external wall options. It can be observed that option 10 contributes to achieving the least energy consumption, followed by 7, 6 and 8, while the maximum energy consumption is with option 3. By considering the total annual energy consumption (the average for all the 14 options) and the gross floor area, the annual energy consumption per square meter (Energy Utilization Index – EUI) of the building was obtained, and found to be about 113 kWh/m2/yr. This is justifiable according to recent studies on residential buildings in KSA that showed EUIs

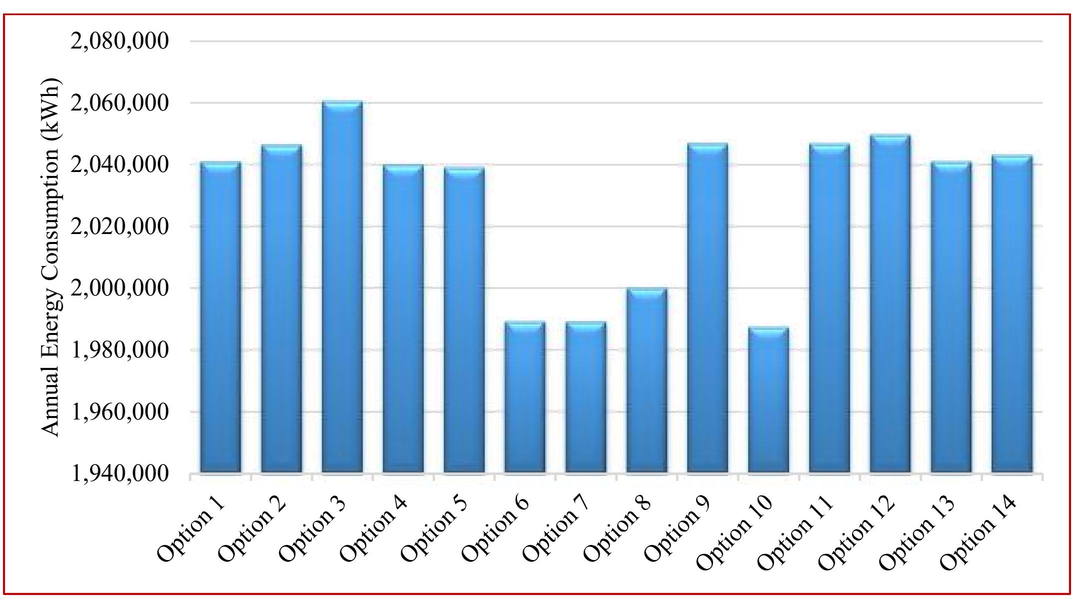

Figure 3: Annual energy consumption of the building with various options.

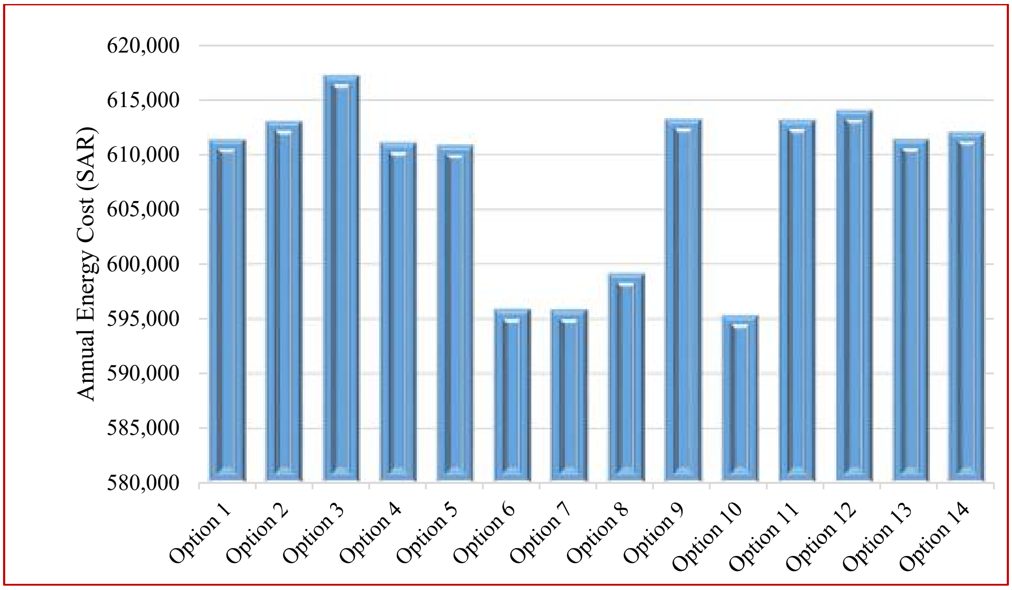

Figure 4: Annual energy cost of the building with various options.

of 176.5 kWh/m2/yr in the study region (Eastern Province)[21] and 228 kWh/m2/yr in Riyadh[22]. The discrepancy in EUIs could be attributed mainly to the change in operating hours of the building. Moreover, based on a manual check of a typical office-cum-commercial building in the study region, the EUI was found to be in the range 180 – 220 kWh/m2/yr.

3.2 Life Cycle Cost

The LCC was estimated in terms of the net present value (NPV)[13], by considering a life span of 20 years, interest rate of 5%, inflation rate of 2% and zero salvage value. The initial cost was estimated by multiplying the wall and glazing areas (m2) with the standard prices (SAR/m2) obtained from the local contractors. The maintenance, replacement and environmental costs were estimated as 2.22%, 2.28% and 1.62% respectively of the initial cost as adopted in similar studies[16], [23]. The operating and maintenance (O&M) cost is the sum of energy and maintenance costs. Table 5 consolidates the results of LCC with component costs and the total NPV for the building with each option; the LCC values are also shown graphically in Figure 6. The results indicate that the existing case (base case) is significantly not advisable as it has the highest initial cost and LCC. The best external wall options with respect to LCC are Options 6 and 7 (with a saving of 7% in LCC compared to the default case, while 3, 4, 5 and 11 share the second position (6% saving in LCC).

A comparison is made among the initial cost, total energy cost and the NPV, as summarized in Table 6. It is interesting to note that Option 3 is the most attractive with respect to the initial cost, while options 6, 7 and 10 are advisable in terms of the total energy consumption and energy cost. However, the NPV (or LCC) has shortlisted options 6 and 7 to be the best cases. So if one would decide on Option 3 based on low initial cost, it would obviously yield the highest energy consumption and hence the highest energy cost (12.35 million SAR). If the choice would be on energy cost, the owner would be left with 3 choices (options 6, 7 and 10), which could then be narrowed down to options 6 and 7 by the LCC approach. The best external wall options (options 6 and 7) have common features such as 12.5mm inner layer of Gypsum Board, 150 mm Concrete Block, 70 mm Polystyrene or Polyurethane insulation layer and an outside layer of 12 mm cement plaster. These findings are promising indicators for decision-makers when selecting the appropriate external wall for the building.

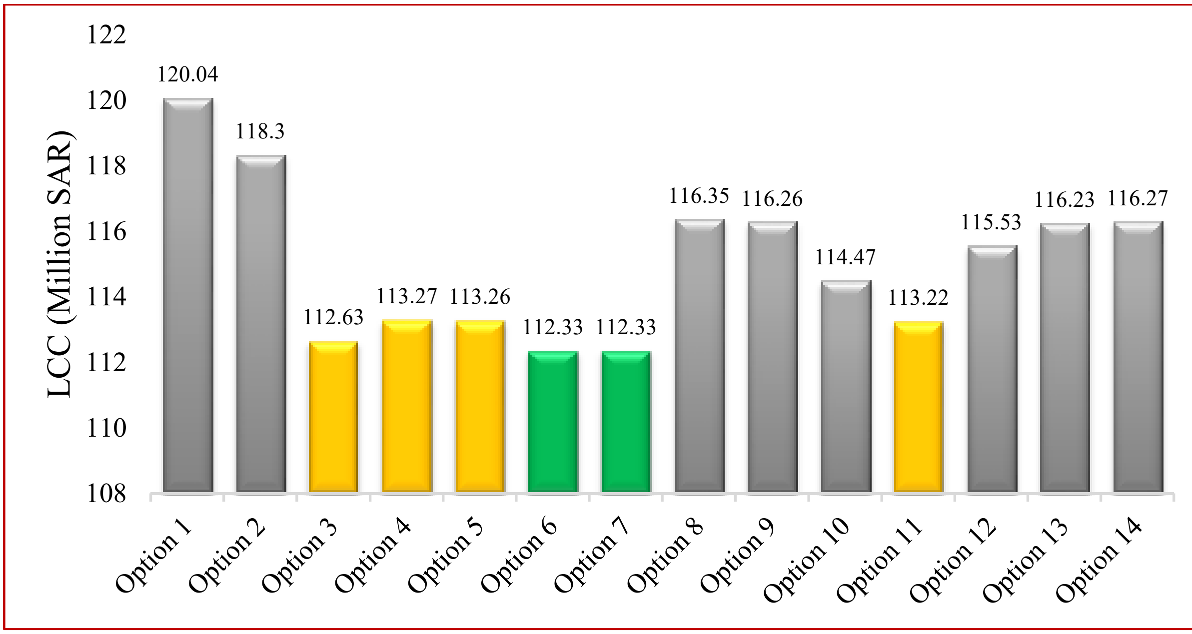

Figure 6: LCC of the building with various external wall options.

Table 5: The LCC of the building with various external wall options

External wall Options	LCC (Million SAR)				
	Initial Cost	O&M	Replacement	Environmental Cost	NPV
Option 1	59.874000	11.925185	2.331116	1.716549	120.04
Option 2	58.437600	11.922066	2.337445	1.721210	118.30
Option 3	53.826000	11.893163	2.353610	1.733113	112.63
Option 4	54.657600	11.804196	2.329975	1.715709	113.27
Option 5	54.657600	11.800142	2.329084	1.715052	113.26
Option 6	54.748320	11.542337	2.271923	1.672962	112.33
Option 7	54.748320	11.541968	2.271842	1.672902	112.33
Option 8	57.681600	11.664527	2.284479	1.682207	116.35
Option 9	56.850000	11.889997	2.338144	1.721724	116.26
Option 10	56.434200	11.570770	2.269945	1.671505	114.47
Option 11	54.506400	11.837335	2.338005	1.721621	113.22
Option 12	56.245200	11.890890	2.341294	1.724044	115.53
Option 13	56.925600	11.860309	2.331243	1.716643	116.23
Option 14	56.925600	11.871084	2.333614	1.718388	116.27

Table 6. Comparison of initial cost, energy cost and LCC

External wall Options	Initial Cost (Million SAR)	Total Energy Cost (Million SAR)	LCC (Million SAR)
Option 1	59.90	12.23	120.04
Option 2	58.44	12.26	118.30
Option 3	53.83	12.35	112.63
Option 4	54.66	12.22	113.27
Option 5	54.66	12.22	113.26
Option 6	54.75	11.92	112.33
Option 7	54.75	11.92	112.33
Option 8	57.68	11.98	116.35
Option 9	56.85	12.27	116.26
Option 10	56.43	11.91	114.47
Option 11	54.51	12.26	113.22
Option 12	56.25	12.28	115.53
Option 13	56.93	12.23	116.23
Option 14	56.93	12.24	116.27

3.3 Uncertainty Analysis

The uncertainties associated with the LCC (NPV) values obtained have been analyzed by Monte Carlo simulation by using Crystal Ball software. The results obtained for the default case (Option 1), and the best cases (Options 6 and 7) are shown in Figures 7, 8 and 9 respectively, that depict the standard deviation, mean and probability distribution for the NPV considering a certainty level of 90%.

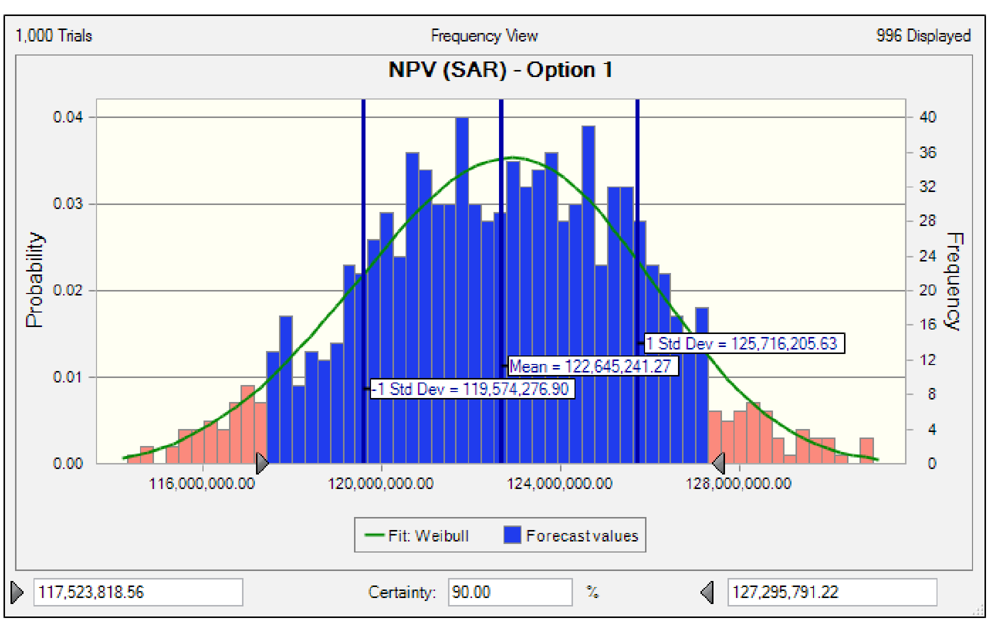

Figure 7: Probability distribution of NPV (LCC) for Option 1.

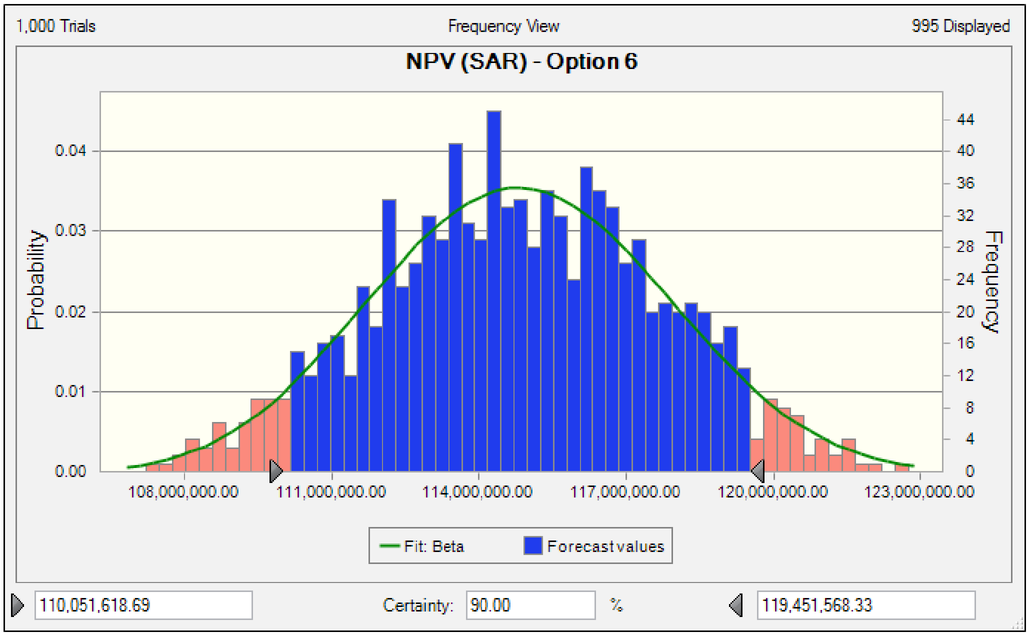

Figure 8: Probability distribution of NPV (LCC) for Option 6.

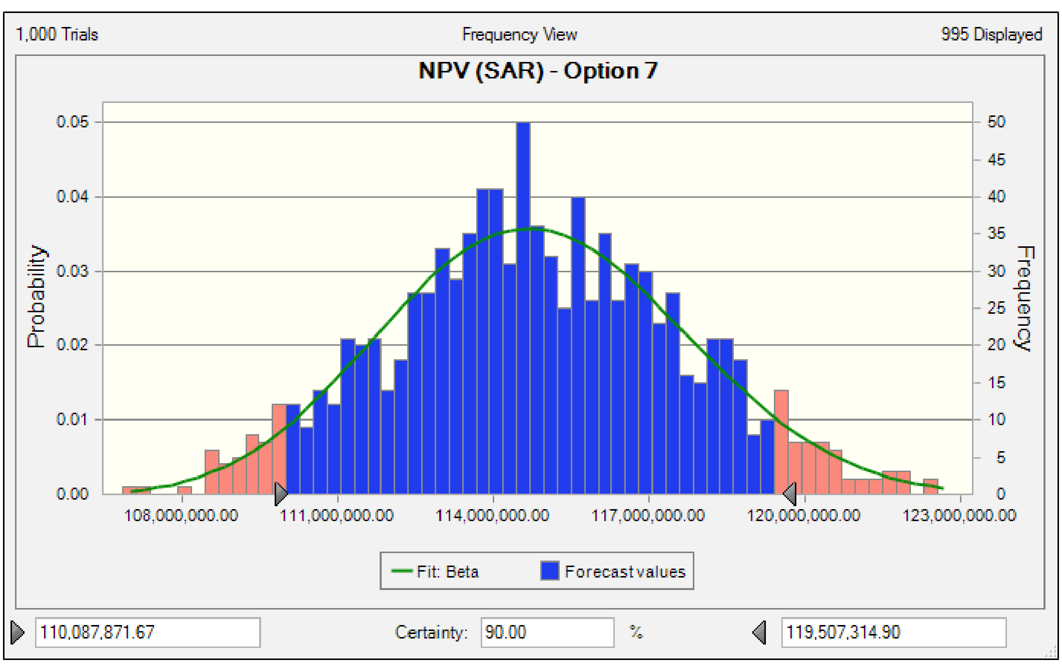

Figure 9: Probability distribution of NPV (LCC) for Option 7.

3.4 Sensitivity Analysis

Figures 10 to 12 represent the results of the sensitivity analysis, which clearly show that in all the cases the initial cost has the highest positive correlation influence on the NPV (57.2%, 61.2% and 55.6% for the base case, Option 5 and Option 6 respectively), the next highest being the replacement cost, followed by the operation and maintenance cost. Similar results were also obtained for the remaining cases.

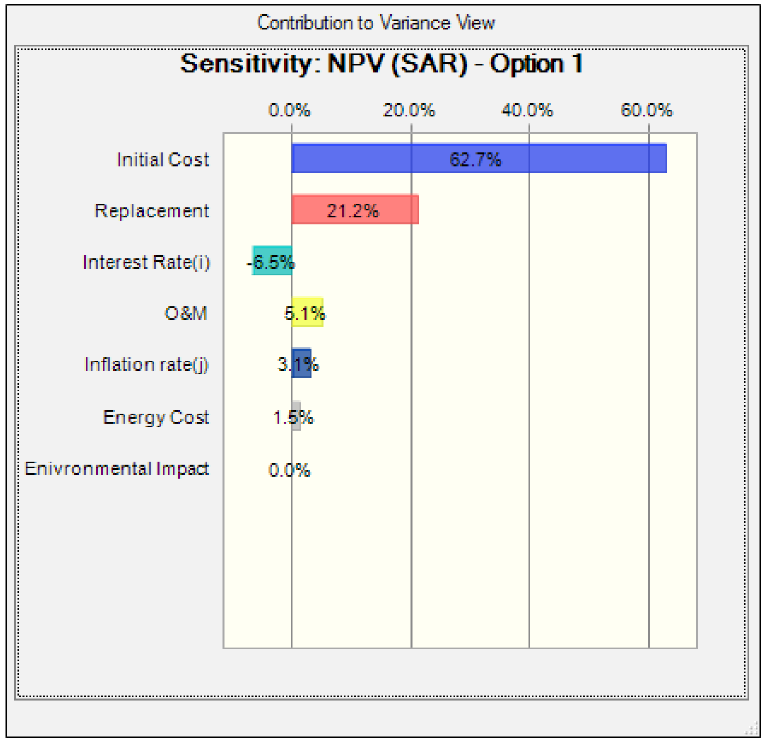

Figure 10: Sensitivity analysis of NPV for Option 1.

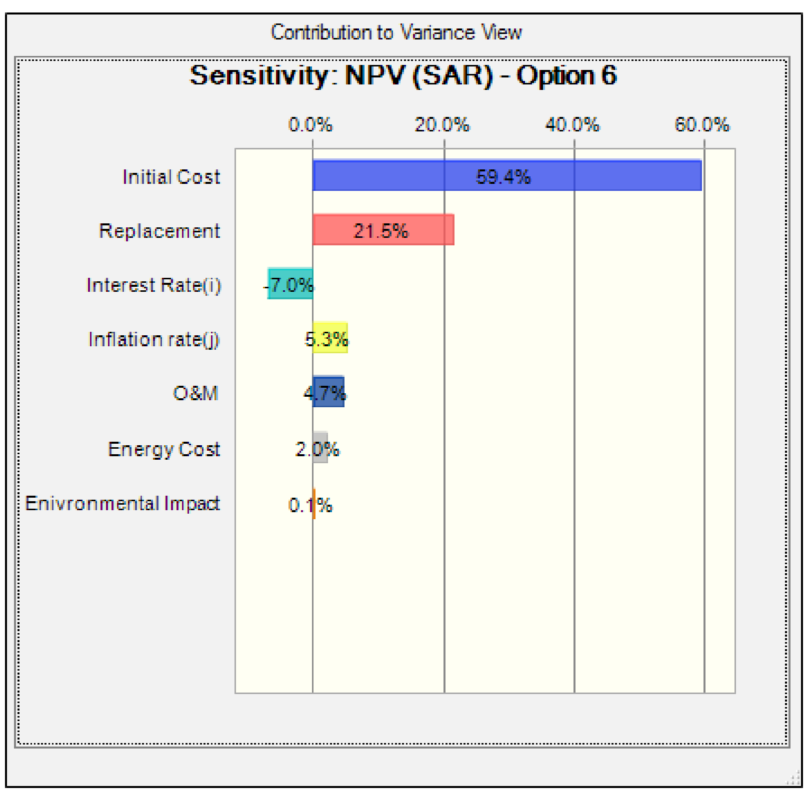

Figure 11: Sensitivity analysis of NPV for Option 6.

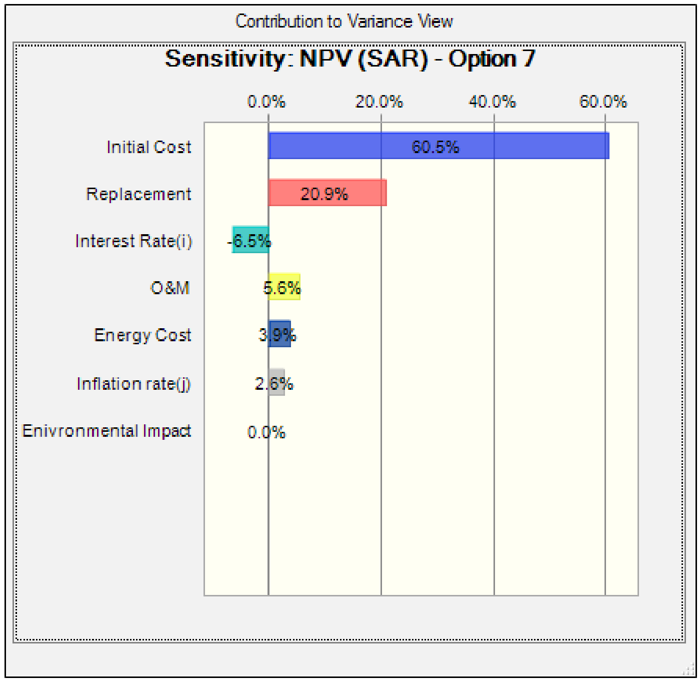

Figure 12: Sensitivity analysis of NPV for Option 7.

3. Conclusion

The current study has estimated LCC of a 20-story office-cum-commercial building in Saudi Arabia, with 14 locally available external wall options. The LCC of the building was estimated in terms of Net Present Value (NPV), for the base case and by considering all the external wall options. Uncertainty and sensitivity analyses have been analyzed by Monte Carlo simulations. The building model was built in Autodesk Revit and the energy simulations were done by using ECOTECT simulation software. The results indicate that:

- The external wall adopted for the building is not recommendable in terms of both initial cost and LCC.
- The best external wall options have been identified to be options 6 and 7 (7 % saving in LCC compared to the base case), which have common features such as 12.5mm inner layer of Gypsum Board, 150 mm Concrete Block, 70 mm Polystyrene or Polyurethane insulation layer and an outside layer of 12 mm cement plaster.
- Option 3 which has the least initial cost contributes to the highest energy consumption (and hence the highest energy cost). So the material selection based on initial cost has turned out to be unadvisable.
- The present LCC approach would enable t he decision-maker to choose the appropriate external wall option from the shortlisted best options 6 and 7.

The current study has focused only on the LCC, so it would be of interest mostly to buildings operated directly by the owner. However, regardless of the running cost being paid by the owner or the tenant, the growing concern on the energy efficiency of buildings demands adoption of all means to reduce the electricity consumption. Extended studies are underway, by considering more external wall options with different types of glazing such as single, double, triple and triple-lowe, and for different types of buildings and locations. Life Cycle Assessment (LCA) of the building with the tested alternatives, with a view to evaluate the environmental impact, is also in progress.

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اختيار مواد بناء الغلاف الخارجي للمباني باستخدام تقنية حساب تكاليف حياة المشروع للمباني التجارية في المملكة العربية السعودية

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ملخص البحث. يعتبر قطاع التشييد في المملكة العربية السعودية الأكبر والاسرع على مستوى دول الخليج العربي. الغلاف الخارجي للمباني له دور هام في أداء الطاقة وتكاليف البناء. وبالرغم من أهمية حساب كلفة دورة حياة المشاريع في المملكة من مرحلة التشييد الى الهدم بغرض اختيار مواد البناء ونظم الانشاء الا ان قليل من الدراسات انجزت في هذا المجال. عملت هذه الدراسة لتسليط الضوء في مرحلة التصميم الأولى على اختيار مواد البناء والانشاء بواسطة استخدام تقنية حساب تكاليف دورة حياة المشروع. تم في هذه الدراسة اختيار مبنى تقليدي تجاري عالي الارتفاع في مدينة الخبر، شرق المملكة العربية السعودية. شملت الدراسة ١٣ نوع من انواع مواد البناء ومقارنتها بالحالة الأساسية والمتمثلة في المبنى القائم ولمدة عشرين سنة من التشغيل. تمت نمذجة المبنى بواسطة استخدام برنامج «ريفيت» ٢٠١٥ وتم حساب استهلاك الطاقة بعمل محاكاة للطاقة باستخدام برنامج «ايكوتيكت» ٢٠١١. تم عمل تحليل اللامحدودية ومقدار التحسس باستخدام برنامج «مونتي كارلو سميوليشن». اظهرت النتائج ان الوضع الراهن للمبنى القائم من حيث اختيار مواد البناء المستخدمة غير موصى به بالنسبة لحساب كلفة التشييد الأساسية وكلفة دورة حياة المشروع. كما ان أفضل غلاف للمبنى يتكون من ٥ ,١٢ مم من ألواح الجبس، ١٥٠ مم طابوق (بلوكات خرسانية)، ٧٠ مم من عازل البوليسترين او البولي يوريثين، و١٢ مم من طبقة اللياسة. أستطاع هذا النوع من مواد البناء، خلال نمذجة المبنى، من تقليل استهلاك الطاقة بنسبة ٧٪ مقارنة بالحالة الأساسية للمبنى القائم.

الكلمات المفتاحية: غلاف المبنى، تكاليف دورة حياة المشروع، مبنى تجاري، التكلفة الأولية، استهلاك الطاقة، مونتي كارلو سميلوليشن.