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A COMPARATIVE STUDY OF APPLYING DIFFERENT ECONOMIC EVALUATION TECHNIQUES TO ASSESS THE CHOICE OF BUILDING MATERIALS IN EDUCATIONAL FACILITIES

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ABSTRACT

Minimizing building construction and operation costs is always a major concern for building stakeholders. Therefore, it is crucial to select an appropriate technique to evaluate the economic performance of the building's component. While economic evaluation techniques vary, including the Life Cycle Cost (LCC) of the building has proved to be an effective measure in reducing the total cost throughout the building's life. In this paper, 3 LCC evaluation techniques are utilized in a comparative case study to determine the best exterior wall assembly choice for a school building. The case study illustrates that each economic evaluation technique can result in a different favorable choice order, even though all LCC evaluation techniques resulted in the best choice. Moreover, including the energy and operation cost can greatly affect the assembly choice. The more thermal resistance an assembly has, the more LCC savings occur, until a certain resistance value, where it becomes less feasible.

Keywords: Building Materials; Life Cycle Cost; Benefit-Cost Ratio; Payback Analysis; Wall Assemblies.

ملخص البحث

يعد الحد من تكاليف البناء والتشغيل مشكلة رئيسية لأعضاء فريق البناء . لذلك ، من المهم اختيار تقنية مناسبة لتقييم الأداء الاقتصادي لمكونات المبنى . على الرغم من اختلاف أساليب التقييم الاقتصادي ، بما في ذلك تكاليف دورة الحياة ، فقد ثبت أن هذا الإجراء فعال في تقليل التكلفة الإجمالية لحياة المبنى . في هذا البحث ، تم استخدام 3 تقنيات لتقييم تكلفة دورة الحياة في دراسة حالة لتحديد أفضل أنواع الجدران الخارجية لمبنى مدرسة . توضح دراسة الحالة أن كل أسلوب تقييم اقتصادي يمكن أن يؤدي إلى ترتيب اختيار مواد مختلف ، على الرغم من أن جميع تقنيات تقييم تكلفة دورة الحياة أسفرت عن أفضل خيار . أيضا تكاليف الطاقة والتشغيل يمكن أن تؤثر بشكل كبير على اختيار نوع الجدار ، كلما ازدادت مقاومة الجدار الحرارية ، كلما حدث توفير في تكلفة دورة الحياة ، حتى تصل إلى قيمة مقاومة معينة ، حيث يصبح الخيار أقل جدوى اقتصاديًا.

الكلمات الدالة: مواد البناء؛ تكلفة دورة الحياة؛ نسبة تكلفة- الفائدة؛ تحليل الاسترداد .

INTRODUCTION

One of the greatest challenges in a project's design phase is the time constrain, which always limits the designer and stakeholders to explore the full potential of their building's economic performance and often leads to a gap in assessing the full cost of building materials correctly. Consequently, the main building's assemblies, such as the exterior walls, are not fully evaluated in terms of economic value during the whole life cycle of the building and the decision of choosing a certain assembly is usually driven by the initial construction and unit cost. Nevertheless, environmental performance, which directly links to the economic performance, is often neglected, therefore, leads to the choice of more uneconomic solutions without evaluating the whole value of a building assembly.

Even when value engineering is applied in a project, it is usually difficult to determine the most suitable economic evaluation technique that can be used to assess the choice of a specific assembly or a specific material over another one. Therefore, this study aims to determine the most suitable economic evaluation techniques for building assemblies in a comparative case study.

PREVIOUS LITERATURE THAT HAVE CARRIED OUT ECONOMIC EVALUATION TO BUILDING MATERIALS

Egan & Iacovelli, 1996 provided a comprehensive LCC guide to wall systems that integrates Exterior Insulation and Finish Systems (EIFS) [1]. Their research covered the comparison of different installation costs and occasional maintenance of wall assemblies throughout their LCC. Egan et. al. provided a detailed LCC calculation for wall assemblies. Moussatche & Languell, 2001 tested different interior flooring materials for K-12 educational facilities. They used LCC analysis that included the initial, operation, maintenance and replacement costs of the selected materials[2]. Moussatche & Languell, 2001 observed that there is a lack of correlation between the initial cost of the flooring material and the LCC result.

Hasan, Vuolle, & Sire´n, 2008 carried out a study to minimize the LCC of a single-family house in Finland by optimizing multiple building assemblies' parameters achieving space heating reductions from 23–49% [3]. Assad, 2011 developed a tool to calculate the LCC of different building envelope assemblies. She included the operational energy costs in the LCC proving its importance over the total LCC value [4].

Karaguzel, Zhang, Lam, & Poh Lam, 2014 performed an LCC analysis and a simple payback calculation to determine the optimum insulation thicknesses for roofs and walls, as well as, glazing units' types for vertical fenestration systems [5]. While Hee et al., 2015 tested different window configurations (orientations, window to wall ratios, and glazing types) and calculated the LCC and payback period (PBP) for multiple combinations [6]. Another research that included the operational energy cost in glazing materials in a commercial office building was carried out by [7]. The research provided a comparison between different glazing materials, using the payback period method, in different climates and cities in the middle east. They concluded that the energy prices have a remarkable effect on the payback period and, consequently, the material choice.

Marzouk, Azab, & Metawie, 2018 achieved the maximum number of points awarded by the Leadership in Energy and Environmental Design (LEED) rating system through optimizing the LCC of building materials alternatives [8]. Marzouk et al. was able to determine through a sensitivity analysis which building systems affect the factors in the LCC the most.

METHODOLOGY

Three different economic evaluation techniques were selected to assess the choice of specific wall assembly configurations. The evaluation techniques are standardized techniques by the ASTM and all generically consider the value of a project's or an element's initial, running and end-of-life costs and savings. The techniques are discussed below in details stating the equations and economic rates used.

ECONOMIC EVALUATION TECHNIQUES

Current Dollar Method: Present Value Life Cycle Cost (PVLCC)

The Life Cycle Method (LCC) is the total of all costs associated with the building's different life stages, from planning to demolition. Basically, all costs linked to the product will eventually be considered in the investment decision. This method is explained in details in the ASTM E917-13 [9] and the following equation summarizes how to calculate the present value of the LCC.

$$\mathbf{PVLCC} = \sum_{i=0}^{N} \frac{C_t}{(1+i)^t} \qquad (1)$$

where:

C_t = the sum of all relevant costs occurring in year t,
N = length of study period, years, and
i = the discount rate.

A modified factor is used to ensure the inclusion of the energy escalation rate, general escalation rate, and discount rate are all taken into consideration [10]

$$real\ interest\ rate\ r = \frac{i-f}{1+f} \quad (2)$$

$$effect\ of\ escalation\ of\ energy\ prices\ r_e = \frac{r-e}{1+e} \quad (3)$$

$$discount\ factor\ for\ energy\ a = \frac{1-[1+r_e]^{-n}}{r_e} \quad (4)$$

$$discount\ factor\ f_r = (1+r)^{-n} \quad (5)$$

where:
i = nominal interest rate
f = inflation rate
e = escalation in energy price

Benefit to Cost Ratio (BCR)

The benefit-to-cost ratio (BCR) is the inclusion of all costs and savings arising from a specific case in a ratio-based equation to assess the feasibility of this option. All the monetary items are converted in the present value form. If the value of the BCR is higher than one this indicates the feasibility of the option in hand and if the BCR is lower than one, that means the option is not economical.

The following equation, from ASTM-E964 [11], shows how the BCR is calculated.

$$BCR = \frac{\sum_{t=0}^{N} \frac{(B_t - C_t)}{(1+i)^t}}{\sum_{t=0}^{N} \frac{I_t}{(1+i)^t}} \quad (5)$$

where:
B_t = benefits in period t; that is, advantages in revenue or performance, measured in dollars, of the building or system as compared with a mutually exclusive alternative,
C_t = costs in period t, excluding investment costs that are to be placed in the denominator for the building or system, less counterpart costs in period t for a mutually exclusive alternative,
I_t = those investment costs in period t on which the investor wishes to maximize the return, less similar investment costs in period t for a mutually exclusive alternative,
i = the discount rate.

Payback Period Analysis

The payback period (PBP) method, similar to the LCC and BCR, includes all economic values associated with the building project in order to estimate the time when a return of 100% of the invested money occurs. All the values are converted to the present value.

The Payback analysis referred to is in ASTM E1121 [12] and the following equation calculates the PBP.

$$\sum_{t=1}^{PB} \left[\frac{(B_t - C_t)}{(1+i)^t}\right] = C_o \quad (6)$$

where:
B_t = benefits in period t; that is, advantages in revenue or performance, measured in dollars, of the building or system as compared with a mutually exclusive alternative,

C_t = costs in period t, excluding investment costs that are to be placed in the denominator for the building or system, less counterpart costs in period t for a mutually exclusive alternative,

C_0 = Initial cost of investment,

i = the discount rate.

INTRODUCTION TO THE CASE STUDY

The aim of this case study is to assess the economic value of different types of building envelope assemblies for a school complex in Jubail, Kingdom of Saudi Arabia (KSA) using the 3 techniques discussed above. The building envelope assemblies chosen for this study are the external wall assemblies. The type of materials chosen for comparative analysis are selected from commonly used materials in large projects and educational facility projects in the KSA.

Overview on the building's details

The building space type for all the buildings in this case study is a school which has a regular K-12 school schedule. The school in the case study is the Intermediate Boys School in Mutrafiah Sector F1.

Jubail is located in zone 0B according to the ASHRAE world climate zones map from the ASHRAE standard 169 – 2013 [13]. Zone "0B" is considered an extreme hot dry climate (desert climate) with temperatures ranging from 38 °C in summer days to 11 °C in winter nights, a variation of 19 °C.

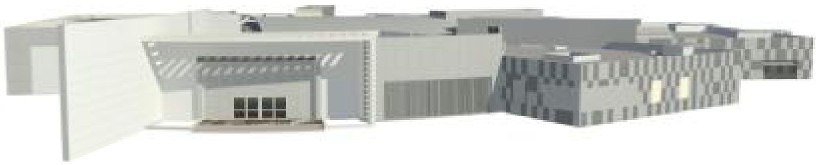

Figure 1 The Intermediate Boys School in Jubail, KSA

The selected construction materials were commonly used materials in the Saudi Arabian construction industry. The construction type and structure system of the school's building is a standard concrete skeleton type. And the building envelope materials are concrete based materials. Expanded Polystyrene is usually the preferred type of insulation for walls and roofs.

The total external walls surface area is 4573m^2. The majority of the external walls designed were double 100mm hollow block concrete masonry units (CMU) with 100mm expanded polystyrene (EPS) in between and proprietary cement sand plaster on both ends.

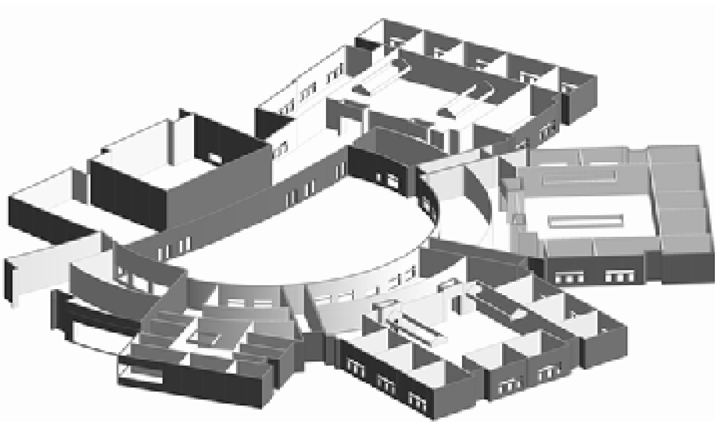

Figure 2 The school's wall assemblies

Table 1 General information about the different wall assemblies considered

Name	Layers					U-value	R-value	Cost/m2	Total Cost	R-US
	1	2	3	4	5	W/m2.k	m2.k/W	SAR	SAR	
Type 1 (Basic)	Proprietary cement sand plaster	Hollow Concrete blocks 100mm	No insulation	No layer	Proprietary cement sand plaster for walls	3.52	**0.28**	81	**396,819**	R-2
Type 2	Proprietary cement sand plaster	Hollow Concrete blocks 100mm	Air thermal layer 50mm	Hollow Concrete blocks 100mm	Proprietary cement sand plaster for walls	0.74	**1.34**	126	**617,274**	R-8
Type 3	Proprietary cement sand plaster	Solid blocks (2000) 100mm	EPS 100mm	Solid blocks (2000) 100mm	Proprietary cement sand plaster for walls	0.36	**2.81**	188	**921,012**	R-16
Type 4 (Suggested)	Proprietary cement sand plaster	Hollow Concrete blocks 100mm	EPS 100mm	Hollow Concrete blocks 100mm	Proprietary cement sand plaster for walls	0.32	**3.11**	180	**881,820**	R-18
Type 5	Proprietary cement sand plaster	Hollow Concrete blocks 100mm	Mineral Wool Insulation 100mm	Hollow Concrete blocks 100mm	Proprietary cement sand plaster for walls	0.31	**3.21**	176	**862,224**	R-19
Type 6	Proprietary cement sand plaster	Hollow Concrete blocks 100mm	EPS 100mm	Hollow Concrete blocks 100mm	Double Calcium silicat cladding + 50 mm mineral wool insulation	0.19	**5.30**	361	**1,768,539**	R-30

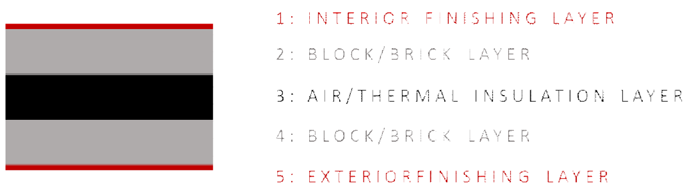

Figure 3 The general wall assembly layers

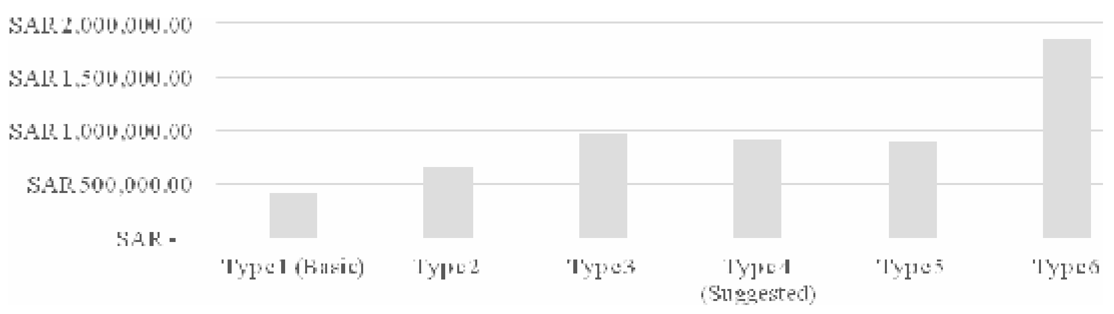

Figure 4 Walls assemblies' initial costs

DATA COLLECTION & ASSUMPTIONS

Initial Cost

The initial costs of materials and installation are estimated from tender prices of similar projects in the same time period and same location as the case study's project. The prices of materials were extracted as price per square meter, later on this was multiplied by the total area of the assembly to acquire the total price of the assembly.

Resale Costs

The resale cost is a depreciated value from the initial cost of the material. The depreciation value is calculated using the Sum of Digits method at year 30. The life time of the wall assembly is assumed to be 100 years [1], and there is no end-of-life salvage value.
The following table summarizes the resale value calculations for the wall assemblies.

Table 2 Depreciation value calculations for the wall assemblies

Name	Initial Cost	Salvage value	Depreciable Cost	Depreciation factor @ yr 30			Depreciation @ yr 30
	SAR	SAR	SAR	n	n(n+1)/2	$2^{*}(n-n_{29})$ / n(n+1)	
Type 1	**SAR 415,611.00**	**0**	**SAR 415,611.00**	**100**	**5050**	**0.01405941**	**SAR 5,843.24**
Type 2	**SAR 646,506.00**	**0**	**SAR 646,506.00**				**SAR 9,089.49**
Type 3	**SAR 964,628.00**	**0**	**SAR 964,628.00**				**SAR 13,562.10**
Type 4	**SAR 923,580.00**	**0**	**SAR 923,580.00**				**SAR 12,984.99**
Type 5	**SAR 903,056.00**	**0**	**SAR 903,056.00**				**SAR 12,696.43**
Type 6	**SAR 1,852,291.00**	**0**	**SAR 1,852,291.00**				**SAR 26,042.11**

Running Costs

Operational Energy Costs

Operational energy costs for each type is considered as the difference between the operational energy cost of the base case and the specific type. The operational energy costs are derived from computer generated energy simulations mimicking the building's structure, materials, location, & activity.

Maintenance & Repair Costs

The maintenance and repair costs for all wall types can be assumed to be the same, therefore, it is safe to omit this specific type of cost from the study and LCC analysis.

ECONOMIC INFORMATION FOR THE ANALYSIS

The economic analysis carried out is a comparative analysis, meaning that all the initial prices, running costs, and resale costs are compared to the base case (type 1) or (R-2).

Types of economic analysis carried out

- PVLCC
- BCR
- PBP

Economic Elements used

- Discount Rate
- Inflation Rate
- Energy Escalation Rate

The selected escalation rate and discount rate were derived from the current rates in the KSA. Where the discount rate was sourced from the Saudi Arabian Monetary Agency's latest announcement in December 2018. While the escalation rate for energy prices was averaged from the last 25 years energy price changes in the KSA [14].

- Study Period

A study period of 30 years is chosen for the comparison. This period is assumed as the normal building's life time as stated in other economic studies [1,15]

ANALYSIS

Assumptions:

Table 3 LCC calculation parameters

Energy escalation rate (*e*)	15%
Discount Rate (*i*)	3%
Inflation Rate (*f*)	2.8%
Study Period (*n*)	30

Initial Analysis

Table 4 LCC calculation parameters

Name	*Initial Cost*	*Annual Operation energy*	*Resale value @ 30 years*	*Annual Operation Cost*
	SAR	*kWh*	*SAR*	*SAR*
Type 1 (Basic)	-	-	-	-
Type 2	***230,895***	***(23,782)***	***(3,246)***	***(4,994)***
Type 3	***549,017***	***(27,872)***	***(7,719)***	***(5,853)***
Type 4 (Suggested)	***507,969***	***(53,018)***	***(7,142)***	***(11,134)***
Type 5	***487,445***	***(55,593)***	***(6,853)***	***(11,675)***
Type 6	***1,436,680***	***(60,592)***	***(20,199)***	***(12,724)***

Using the PVLCC method
Given that:
n =30; i = 3%; f = 2.8%; e = 15%,

$$r = \frac{i-f}{1+f} = \frac{0.03-0.028}{1+0.028} = 0.0019$$

$$r_e = \frac{r-e}{1+e} = \frac{0.0019-0.15}{1+0.15} = -0.1287$$

$$a = \frac{1-[1+r_e]^{-n}}{r_e} = \frac{1-[1+(-0.1287)]^{-30}}{-0.1287} = 477.396$$

$$f_r = (1+r)^{-n} = (1+0.0019)^{30} = 0.9434$$

Saving/Losses in LCC using Wall Type 4 **=** PV of difference between Type 4 and Basic wall (Initial construction & materials cost + Resale value + annual operation costs)

PV Difference in Initial construction & Material cost= Type 1 initial value – Type 4 initial value = 415,611 – 923,580 = SAR – 507,969

PV savings in resale value = f_r × (Resale Value of wall 1 – Resale Value of wall 4) = $0.9434 \times (5{,}843 - 12{,}984$) = SAR 6,737

PV savings in annual operation costs = a × (annual costs of wall 1 – annual cost of original)= $477.396 \times 53{,}018\, kWh \times 0.21 \frac{SAR}{kWh}$ = SAR 5,315,224

Total savings/losses = –507,969 + 6,737 + 5,315,224 = 4,765,605 SAR
This means using wall type 4 will **save SAR 4,765,605** than using the basic wall type through the building's total life cycle (30 years), even though the initial material and construction cost of basic type 1 is **SAR 507,969 cheaper** than type 4.

Using the BCR method

$$BCR = \left(\sum_{t=0}^{N} (B_t - C_t)/(1+i)^t\right) / \left(\sum_{t=0}^{N} I_t/(1+i)^t\right) = benefits/costs$$

Using the PBP method

Table 5 Payback analysis calculation

Years	**Annual Energy savings**	**factor for PV energy savings (B_t)**	**PV energy savings**	**PV Resale savings (B_t)**	**PV maintenance costs (C_t)**	$\frac{(B_t - C_t)}{(1+i)^t}$	$\sum_{t=1}^{PB}\left[\frac{(B_t - C_t)}{(1+i)^t}\right] - C_o$
0							C_o=(507,969)
1	11,134	1.15	12,779	0	0	12,779	(495,190)
2	11,134	1.32	14,667	0	0	14,667	(480,523)
3	11,134	1.51	16,835	0	0	16,835	(463,688)
4	11,134	1.74	19,322	0	0	19,322	(444,366)
5	11,134	1.99	22,177	0	0	22,177	(422,188)
6	11,134	2.29	25,455	0	0	25,455	(396,734)
7	11,134	2.62	29,216	0	0	29,216	(367,518)
8	11,134	3.01	33,533	0	0	33,533	(333,985)
9	11,134	3.46	38,488	0	0	38,488	(295,497)
10	11,134	3.97	44,175	0	0	44,175	(251,322)
11	11,134	4.55	50,703	0	0	50,703	(200,619)
12	11,134	5.23	58,195	0	0	58,195	(142,423)
13	11,134	6.00	66,795	0	0	66,795	(75,629)
14	11,134	6.89	76,665	0	0	76,665	1,036
15	11,134	7.90	87,993	0	0	87,993	89,029
16	11,134	9.07	100,996	0	0	100,996	190,024
17	11,134	10.41	115,919	0	0	115,919	305,944
18	11,134	11.95	133,048	0	0	133,048	438,992
19	11,134	13.72	152,709	0	0	152,709	591,701
20	11,134	15.74	175,274	0	0	175,274	766,975
21	11,134	18.07	201,174	0	0	201,174	968,148
22	11,134	20.74	230,900	0	0	230,900	1,199,049
23	11,134	23.80	265,020	0	0	265,020	1,464,069
24	11,134	27.32	304,181	0	0	304,181	1,768,250
25	11,134	31.36	349,129	0	(48,387.64)	300,741	2,068,991
26	11,134	35.99	400,719	0	0	400,719	2,469,710
27	11,134	41.31	459,932	0	0	459,932	2,929,641
28	11,134	47.41	527,894	0	0	527,894	3,457,536
29	11,134	54.42	605,900	0	0	605,900	4,063,436
30	11,134	62.46	695,432	6,737.22	0	702,169	4,765,605

The payback period is when the cash flow turns from negative values (cost) to positive values (savings) which happened in this case between year 13 and 14. To get the exact payback period the following equation is used.

$$PBP = (n-1) + \frac{0 - C_{n-1}}{C_n - C_{n-1}} \qquad (7)$$

where:

n = 1st year with positive cashflow

C_n = 1st positive cashflow

$$PBP = (14-1) + \frac{0-(-75{,}629)}{1{,}036-(-75{,}629)} = 13.986\ years$$

RESULTS

COMPARISON

PVLCC method Results

The LCC results show that type 5 (R-19) is the best option compared to type 1 (R-2), even though its annual energy savings is lower than type 6 (R-30). However, the initial cost of type 5 is much lower than type 6 which makes the savings created by type 6 in the energy consumption less significant. Even though type 2 (R-8) initial cost is significantly lower than all the other types, it did not catch up in the energy savings such as type 4, 5 and 6, making type 2 the least favorable option.

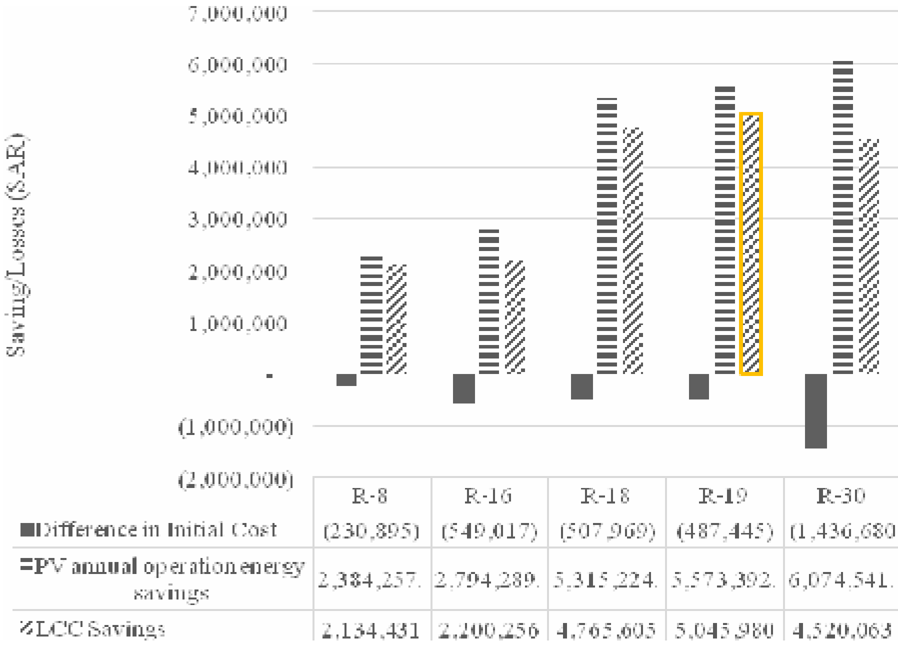

Figure 5: Breakdown of wall types LCC using the PVLCC method.

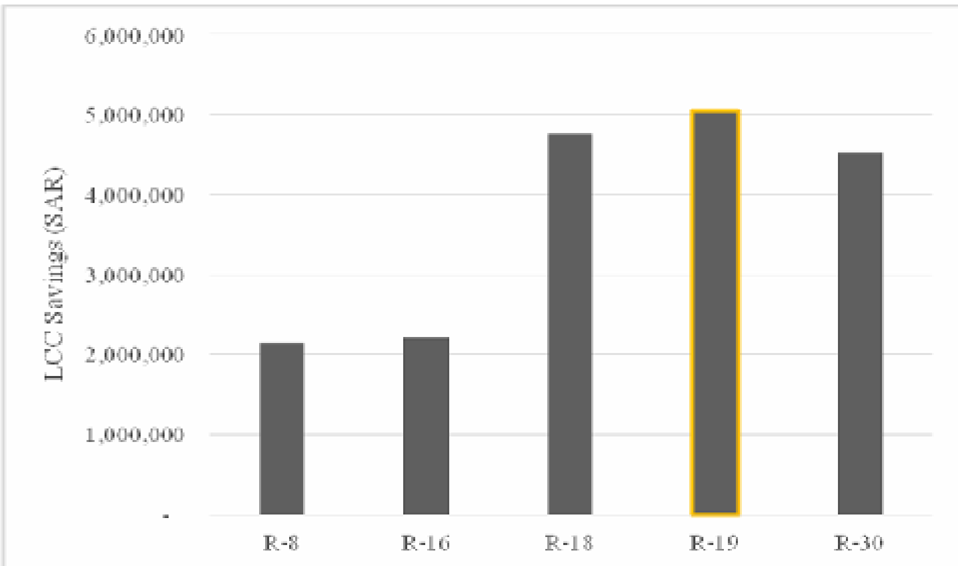

Figure 6: LCC savings of wall assemblies using the PVLCC method.

BCR method results

The benefit-to-cost ratio results of all assemblies compared to type 1 (R-2) are greater than 1, which means that they are all feasible. And the highest ratio was 10.4 by type 5 (R-19) which was the favorable type in the previously shown PVLCC analysis. However, that does not mean the highest ratio is always the most favorable type since the ratios solely depends on the initial value of each individual type and they all have nothing in common in-between to compare the ratios to.

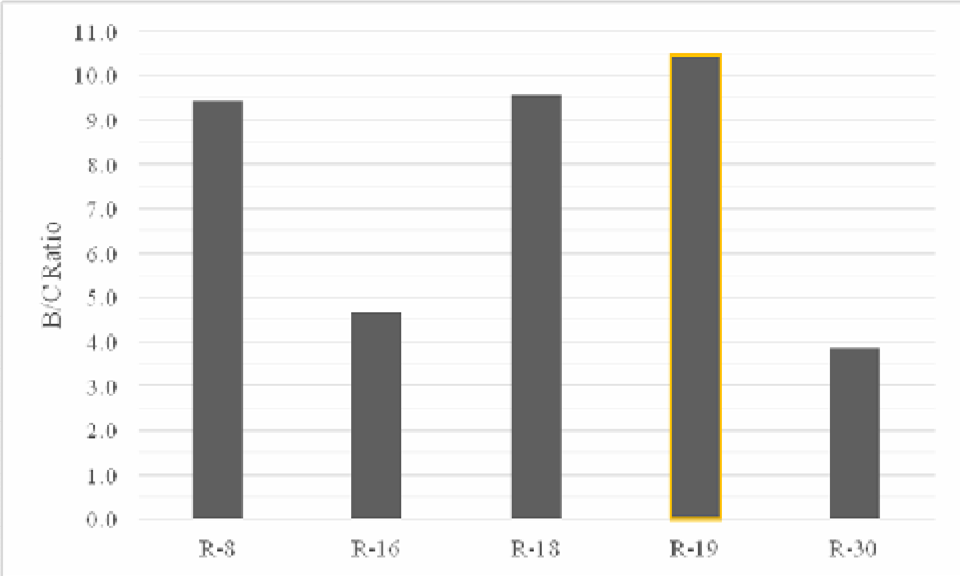

Figure 7: Benefit Cost Ratio for wall assemblies.

PBP method results

Finally, the payback period of type 5 (R-19) was the least, 13.42 years, followed by type 4 (R-18) with half a year difference (type 4 has a 6% higher payback period). Unsurprisingly, type 6 (R-30) had the highest payback period, nearly 20 years, and this is due to its initial cost is higher than all other types (type 6 has a 32% higher payback period). While type 2 (R-8) has a payback of 14 years, which is only 8% higher than type 5, and this is due to its very low initial cost.

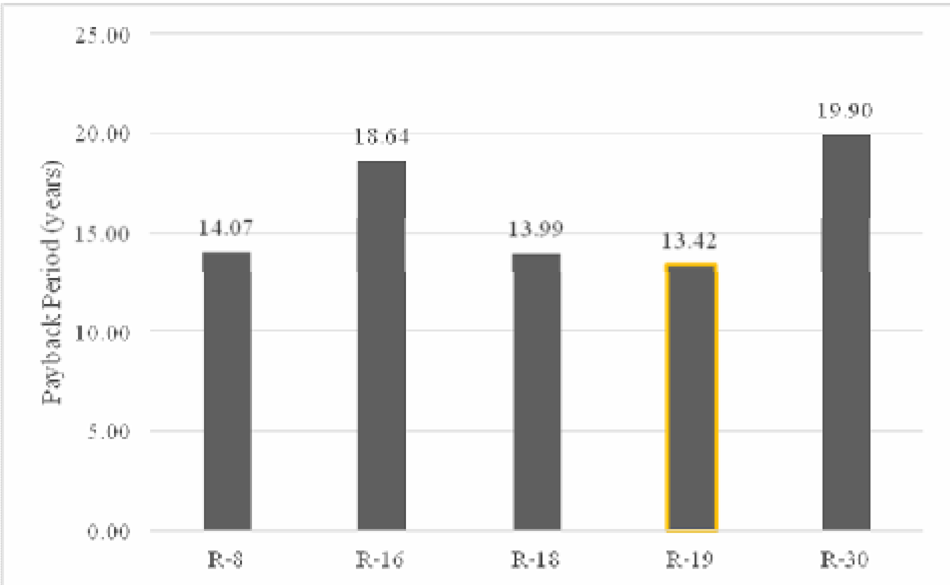

Figure 8: Payback period of wall assemblies.

CONCLUSION & RECOMMENDATIONS

This study aimed to select the most economic wall assembly using 3 different economic evaluation techniques. Wall assembly type 5 (R-19) was the best choice in all 3 evaluation methods, even though the ranking of other types was along the 3 methods was not the same.
As a conclusion of testing the 3 evaluation techniques, it was observed that each method will explore the options in a different way; the PVLCC method took into consideration the absolute net profit/loss of choosing a certain type over the other, whereas the BCR was solely focusing on the net profit/loss compared to the initial investment minimizing the effect of interest rates uncertainty. And finally, the payback period method focuses on the fastest profit return ignoring the benefits and costs of the choices over their remaining service life, which can be feasible in short term comparisons rather than long ones.
The study also asserts the importance of including the operational energy costs of building material in the evaluation of their economic performance, showing that it constitutes of nearly 85% of the total LCC of the wall assemblies. Nonetheless, the best option, economically, is not always the most energy efficient alternative. Further evaluation can be carried out using different economic rates as a predictive sensitivity analysis to ensure the choice of materials is considering all risky economic changes.

NOMENCLATURE

LCC	Life Cycle Cost
BCR	Benefit-to-Cost Ratio
PBP	Payback Period
PV	Present Value

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