Life Cycle Cost-Implications of Building Envelope Decisions

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NATURE OF BUILDING ENVELOPE DECISIONS

Choosing building envelope systems and materials by its very nature requires making many decisions pertaining to the design, maintenance, repair and replacement of such systems. Decisions are made based on the requirements, which are directly or indirectly related to the needs of the client, requirements to resist environmental loads, and requirements dictated by prevalent local practices, standards, and codes. Prudent owners demand that the successful building envelope choice meet all the functional requirements cost-effectively.

Initial Cost and Cost-effectiveness

Designers often feel that owners view cost-effectiveness as the same as lowest initial cost. Proper articulation of other than initial costs makes it more likely to draw the owner's attention to life cycle costs. Most business owners are familiar with capital investment decisions that form the backbone of any business enterprise. These decisions require analysis that takes into account initial and future cash flow considerations. The basic methodology to deal with business investment decisions has not changed in several years and can be found in standard college courses and textbooks on financial management and engineering economics and architectural economics such as Brigham(1991), Riggs(1986) and Mann (1992). Furthermore these types of analysis are now relatively easy to conduct using built in functions of business calculators.

Building Envelope Decisions as Business Investment Decisions

Treating building envelope decisions as a capital investment decision, similar to business investment decisions (such as buying one type of production equipment or another, or buying one type of computer or another), allows designers to apply the techniques that the business owners understand. Clearly if one alternative has initial costs more than another, the owner needs justification on how the higher initial cost alternative will save them money or benefit them in the future. The future cost savings or benefits need to be compared to the initial increased cost to determine if the alternative with more initial cost is worth considering.

There is one major difference between building envelope decisions and other business investment decisions: building envelope investments rarely produce a revenue stream like other business investments. They only produce a cost stream. The question of cost-effectiveness of alternatives should therefore be addressed by asking the question: Does the future cost reduction of one alternative justify paying more for it in the present? For example consider systems A and B. System A has an initial cost 25% more than that of B. If the yearly maintenance costs and periodic repair and eventual replacement costs of A are also higher than that of B, and it has no other future benefits then no further analysis is required. Alternative B is clearly cost-effective over A. On the other hand if the yearly maintenance costs and periodic repair and eventual replacement costs of A are lower than B, then at what point will A be more cost-effective than B?

When future costs are involved two things are necessary to estimate their impact:

a) The timing and amount of the future cost

b) Discounting

Timing of cost is indicated relative to the base year. The amounts of future costs are generally stated in terms of base year values. Discounting acknowledges the time value of money. The time value of money is a measure of the earning power of money compared to a base year. It is different from inflation, which is a measure of the purchasing power of money compared to a base year. Discounting recognizes that a future cash flow stream is equivalent to a lesser base year amount because of the power of interest compounding.

In typical business investment decisions the future cash flow stream is converted to its equivalent value in the base year (present) by applying the selected discount factor. The net present value is then calculated and compared for each alternative. In building economic decisions this is similar to calculating the net present value by a method often referred to as Life Cycle Costing (LCC). Other types of decision-making criteria include:

a) payback - time required for the cumulative savings to equal the added initial investment

b) savings to investment ratio (SIR) - a ratio of the discounted net present value of savings to the increased initial investment

c) internal rate of return (IRR) - or the rate of return of the increased initial investment resulting in the future savings.

There are ASTM standards for each of these decision criteria. Readers will find Marshall (1990) a useful reference as well.

INITIAL COSTS AND FUTURE COSTS

Initial Costs

To facilitate economic analysis of building envelope decisions as business investment decisions, it is necessary to identify the initial costs and future costs of the various alternatives. Initial cost of an alternative is the sum of all costs, incurred at the time of implementation. Initial costs may be taken from the received bids, or estimates prepared as a part of a consultant's report.

Future Costs

Future costs related to building envelope are divided into annually recurring maintenance and operating costs and non-recurring operating and maintenance costs and capital costs. The annually recurring costs typically include: costs associated with winter time net heat loss and summer time net heat gain, cost of visual inspection, and cost of general preventative maintenance. Non-annually recurring operating and maintenance costs generally include: cost of system specific preventative maintenance (e.g. replacement of failed sealed units on windows or tuckpointing), cost of non-destructive evaluation and cost allowance for minor repairs. Non-annually recurring capital costs includes items such as major repair costs or complete replacement costs. Examples of non-annually recurring capital costs include: window replacement, recladding, roof restoration, roof flashing restoration, masonry restoration and repairs of large areas of building enclosure.

Study Period and Life Expectancy

Generally, future costs are considered over the study period of the decision analysis. For instance, if the owner will keep the building for 40 years, all costs that occur over the 40 years will need to be considered. If an alternative for this owner has a life expectancy of 15 years, its replacement cost will be considered at 15, and 30 years along with the other annually recurring and annually non-recurring costs. If the study period does not coincide with the life of the alternative, a salvage value may be assessed to the alternative. There are different techniques available for calculating salvage value. A simplified straight-line depreciation can be applied without much error in analyzing building envelope investment decisions. The life expectancy of the alternative will impact the net present value, but it is not required that all alternatives have the same life expectancy in performing the analysis nor is it required that life expectancy be the same as the study period.

ECONOMIC ANALYSIS AND BUILDING ENVELOPE DECISIONS

The application of economic analysis to building envelope investments is not new. Economic analysis has been widely used to determine the optimum level of insulation in building envelopes (Masonry Council 1982). This document shows an example where three different levels of insulation are considered for a masonry wall. Several economic analysis techniques are used to show the manner in which a decision can be made to select the cost-effective option. Griffin et al (1995) have shown the use of life cycle costing in determining the optimum roof slope to be 2%. In another example, they use life cycle costing to show that additional investment to provide slope, will provide an equivalent return on that investment of 37%, when compared to the alternative of not providing slope and an early roof failure. They also show an example where the life cycle costing analysis is done between a protected membrane roof (PMR) and a conventional roof to show how the increased cost of PMR more than pays for itself over a life cycle study period of 20 years.

Life cycle costing was also done of a re-cover over an existing wet roof by Desjarlais (1995). They used the Internal Rate of Return (IRR) as a measure to compare the cost-effectiveness of initial investment of the recover option which resulted in a decreased operating and maintenance costs. They have also shown the impact to different maintenance rates on the IRR.

An illustration on the use of LCC to choose between patching an existing 30 year old BUR and installing a new single ply roof is shown by Melvin (1992). Examples that apply to different building decisions that are can also be found in ASTM standards and Marshall (1990).

STEPS IN CONDUCTING BUILDING ENVELOPE ECONOMIC ANALYSIS

Step 1 - Define the objective

Before an economic analysis is performed to evaluate a building envelope investment, the objective of the evaluation has to be defined. The objective may be to select the cost-effective system; to select the cost-effective R-value of insulation; to decide if it is cost-effective to defer maintenance; or to decide if it is cost-effective to repair an old system or replace it. The objective will lead to the formulation of alternatives. It should be noted that factors other than economic factors are also important and need to be considered. Although life cycle costing cannot be directly used to consider these other factors there are means to account for these factors in a quantitative manner along with cost factors (Norris et al, 1995).

Step 2 - Identify feasible alternatives

The second step is to identify feasible alternatives for accomplishing the objectives. It is imperative to identify functionally comparable alternatives. Alternatives that do not meet the functional requirements should not be considered.

Step 3 - Identify the study period

It is necessary to determine the study period over which the economic analysis will be performed. This may or may not be the same as the life expectancy of the alternatives. In general the effect of discounting diminishes the impact of costs and revenues significantly on the outcomes beyond a 25-year study period. Furthermore, future costs may become more unpredictable as the study period is increased. For most building envelope related evaluations, the error by limiting the study period to 30 years is minimal.

Step 4 - Compile data for each alternative

For each of the alternatives, it is necessary to determine initial costs, the annually recurring costs, the non-annually recurring costs and their timing, and any costs associated with end-of-life replacement. Where the life expectancy of the alternative is longer than the study period, an appropriate salvage value may need to be assigned to account for the alternative's potential to remain functional. For most building envelope related evaluations, salvage value based on straight line pro-ration will provide acceptable results. In most standard analyses it is assumed that the costs occur at the end of the year. The time based cost profile of the alternative is called its cash flow stream. A cash flow stream should be developed for each alternative.

If the rate of inflation applies equally to all costs, the calculations can be based on non-inflated values or constant dollar values using a discount rate that is net of inflation rate. Energy and disposal costs are likely going to be the only costs that may rise at a faster rate than the general inflation and may need special treatment. Marshall (1990) provides more details on the impact to inflation, taxes, depreciation, financing and study period.

Step 5 - Select an appropriate discount rate

A discount rate is used to discount the future cash flows to their present value. Typically, the discount rate can be thought of as the interest rate that the user would be expected to earn if they chose not to invest in the investment. For businesses, the discount rate reflects the return on investment they expect to make on their investments. For homeowners, it reflects the interest rate of their mortgage or term deposits.

Proper consideration has to be made when selecting discount rates. Uncertainties in the discount rate can easily be handled by conducting the analysis for different rates and noting the variations in the outcome. This type of analysis is also called sensitivity analysis.

Step 6 - Discount future cash flow streams

This step ensures that the value of all future project income and expenditures reflects the effect that time and interest has on money values. It allows one to compare a stream of future costs and benefits by transforming them to the same point in time, generally the base year or the present - hence the term present value analysis. Future and annual time equivalencies are also possible to do and desirable under some circumstances.

Step 7 - Select the cost-effective alternative

Once the discounted values are calculated, the economic measure of interest can be calculated i.e., Life Cycle Cost (LCC) or the Net Present Value, Discounted Payback, Savings to Investment Ratio (SIR) or Internal Rate of Return (IRR). This step can be performed using standard formula for discounting - Marshall (1990), ASTM standards, or using a computer program such as Building Life Cycle Costing developed at the National Institute of Standards and Testing, Gaithersburg, MD.

The choice of the alternative based on the economic measure can then be made i.e. select the alternative with the lowest LCC, or with the greatest SIR greater than 1, or the greatest IRR greater than the discount rate. A sensitivity analysis can be performed to see how the outcome changes if one of the parameters such as cost, life expectancy or discount rate changes. A decision as to the most cost-effective alternative can then be made

EXAMPLES/CASE STUDIES

The following examples demonstrate some of the information presented earlier based on common situations encountered. The examples relate to roofing but can be extended to other building envelope situations. As is evident in these examples the use of economic analysis creates an opportunity for designers to promote better cost driven decisions.

Example 1

SITUATION:

An owner prefers a hybrid 4-ply BUR system for a new 30,000 sq. ft. roof. This is called alternative A. The cost of this roof is estimated to be $180,000 and includes upgraded membrane flashing and it comes with a manufacturer's warranty of 15 years. The manufacturer estimates that other than normal preventative maintenance and visual inspection by the owner's representatives there is no other maintenance required. The maintenance cost is estimated to be $1,800/year for the life of the roof that is estimated to be 25 years.

A contractor who can provide a conventional 4-ply BUR system with glass felts for $150,000 has approached the owner. This is called alternative B. The contractor only provides a standard association warranty of 2 years. The maintenance cost of this roof is estimated to be $3,600/year for the life of the roof. Flashing repairs may be required around year 15 at a cost of $8,000. This will ensure that the roof will last 25 years.

The owner retains a designer to determine whether alternative A is better than B over the 25 years of expected life of the systems based on life cycle costs. The discount rate for the owner is 10%.

SOLUTION:

Steps 1 to 5 have been completed in the above situation. The next step is to discount future cash flow streams. The cash flow streams for the two alternatives are shown in a cash flow diagram, Figures 1A and 1B. The BLCC program version 4.2 was used to complete step 5 and the results obtained are shown in Table 1.

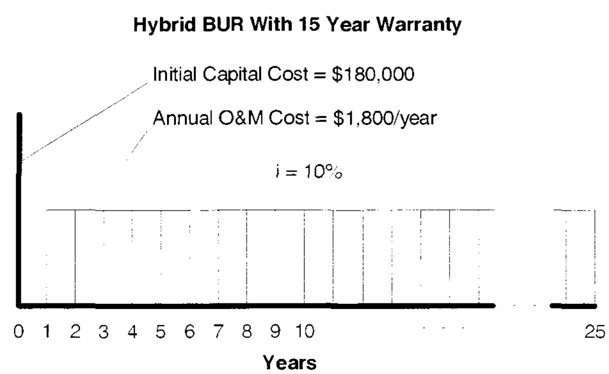


Figure 1A - Example 1, Alternative A

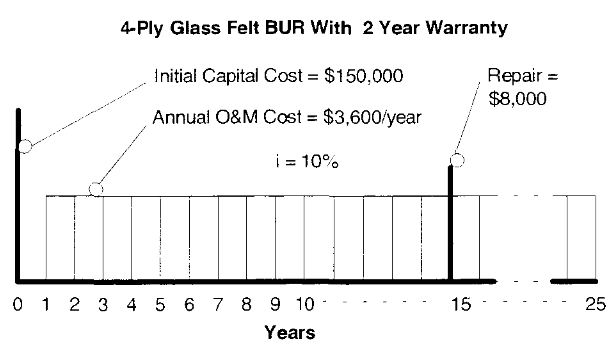


Figure 1B - Example 1, Alternative B

Cost Category	Alternative A Hybrid BUR 15 Yr. Warranty	Alternative B 4-Ply Glass Felt BUR 2 Yr. Warranty	Cost B - Cost A
Initial Capital Cost	$180,000	$150,000	($30,000)
Present Value of operating costs	$16,339	$34,592	$18,254
Present Value of replacement costs			
Present Value of salvage			
Sub-Total of PV of costs and salvage	16,339	34,592	$18,254
Total Life Cycle Cost	$196,339	$184,593	($11,746)

Table 1 - Cost Summary, Example 1

Based on the above results it is seen that increased initial cost of alternative A of $30,000 is larger than the present value of the savings of future costs of $18,254.This cost saving of the client's preferred alternative A is lesser than it's initial cost outlay. The LCC of A is more than B by $11,746 and therefore makes B cost-effective over A.The SIR is calculated as the ratio of the savings of $18,254 to the increased initial investment of $30,000 and gives a value of 0.61.This is less than 1 indicating once again that the alternative A is not cost-effective. Simple payback can be calculated as the number of years it takes to payback the initial investment not accounting for the effects of discounting on the savings.The yearly savings are $3,600-$1,800 = $1,800. Simple payback of the initial increased investment of $30,000 will be $30,000/$1,800 = 17 years.

Example 2

SITUATION:

An owner of a 50,000 sq. ft. facility has a new roof installed for $250,000. The designer approached the owner to suggest that an inspection and maintenance program should be implemented to ensure that the 20-year life of the roof is realized. It is determined that it would cost $3,000/year to implement such a program.The designer estimates that the consequence of not maintaining the roof is a reduced life expectancy from 20 to 15 years. The owner does not mind the reduced 5 years if it makes business sense to do so i.e. if it is cost-effective. Assuming 10% discount rate the designer is required to determine the answer for the owner.

SOLUTION:

Steps 1, 2, 4 and 5 have been completed in the above situation.The study period is taken as 20 years to coincide with the life expectancy of the roof with preventative maintenance. The next step is to discount future cash flow streams. The cash flow streams for the two alternatives are shown in a cash flow diagram, Figures 2A and 2B . The BLCC program version 4.2 was used to complete step 5 and the results obtained are shown in Table 2.

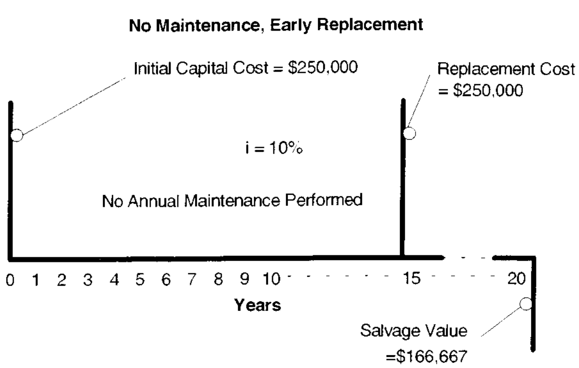


Figure 2A - Cash Flow, Example 2, Alternative A

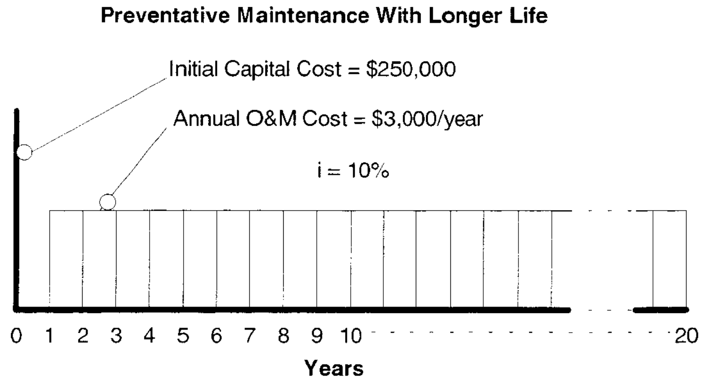


Figure 2B - Cash Flow, Example 2, Alternative B

Cost Category	Alternative A No Maintenance	Alternative B Preventative Maintenance	Cost B - Cost A
Initial Capital Cost	$250,000	$250,000	$0
Present Value of operating costs	$0	$25,541	$25,541
Present Value of replacement costs	$59,848	$0	($59,848)
Present Value of salvage	($24,786)	$0	$24,786
Sub-Total of PV of costs and salvage	$35,062	$25,541	($9,521)
Total Life Cycle Cost	$285,062	$275,541	($9,521)

Table 2 - Cost Summary, Example 2

In this particular instance, there is no change in the initial investment. However, if the roof is maintained at a cost of $3,000/year or approximately 1.2% of the initial cost, then preventative maintenance is cost-effective. In fact for the discount rate of 10%, preventative maintenance will be cost-effective as long as the costs are below approximately $4,000/year or 1.6% of the initial cost. Calculations with a higher discount rate will tend to favor Alternative A. Lower than 15 year life for Alternative A will favor Alternative B.

The above analysis does not account for any water leakage incidence and associated costs. Such incidences can only strengthen the case for Alternative B. It is possible to conclude from the above scenario that as long as the maintenance costs are managed to below 2%, Alternative B will be more cost-effective.

Example 3

SITUATION:

A consultant just completed a survey of a 50,000 sq. ft. facility for an owner. The consultant has determined that the 10-year old roof needs repair and maintenance to realize a life of 10 more years without which it is difficult to say if it can even last 5 more years.The immediate repair costs are $10,000 and thereafter the maintenance costs are $5,000 per year. At the end of their life, the roofs will be replaced with the same type of roof costing $250,000 and requiring similar levels of annual maintenance.The owner needs cost justification from the consultant for the recommended repair work based on a discount factor of 10% and a study period of 20 years.

SOLUTION:

Steps 1 to 5 have been completed in the above situation.The next step is to discount future cash flow streams.The cash flow streams for the two alternatives are shown in a cash flow diagram, Figures 3A and 3B.The BLCC program version 4.2 was used to complete step 5 and the results obtained are shown in Table 3.

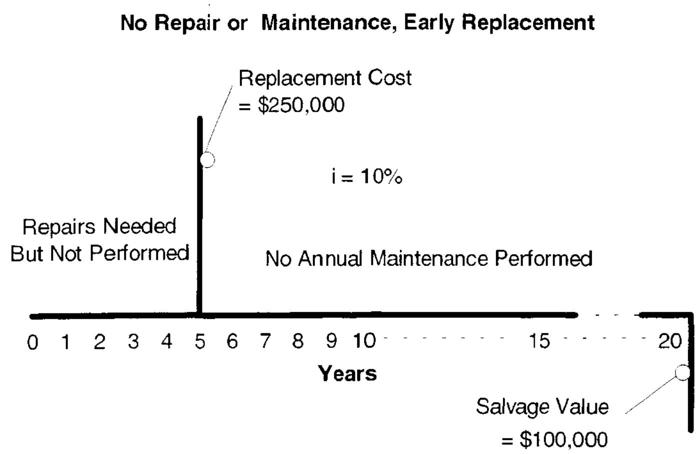
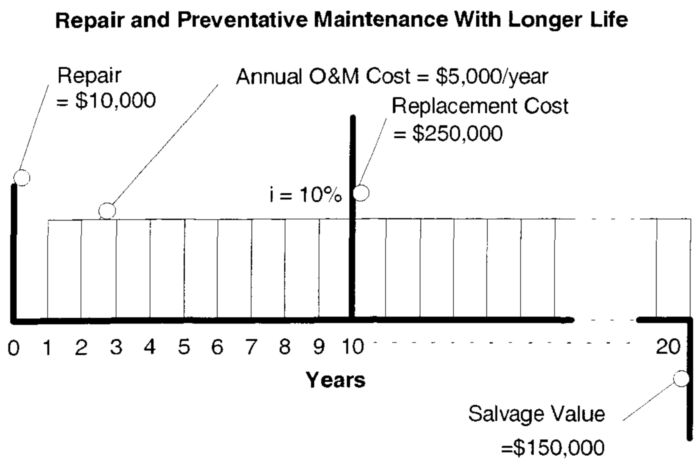


Figure 3A - Cash Flow, Example 3, Alternative A



Cost Category	Alternative A No Repair or Maintenance	Alternative B Repair With Preventative Maintenance	Cost B - Cost A
Initial Capital Cost	$0	$10.000	$10.000
Present Value of operating costs	$0	$42.568	$42.568
Present Value of replacement costs	$155.230	$96.386	($58 845)
Present Value of salvage	($14.865)	($22.298)	($7.433)
Sub-Total of PV of costs and salvage	$140.365	$116.656	($23.709)
Total Life Cycle Cost	$140,365	$126,656	($13,709)

Figure 3B - Cash Flow, Example 3, Alternative B

Table 3 - Cost Summary, Example 3

The above example shows that the LCC of alternative A is higher than alternative B by $13,709 and therefore it is more cost-effective to carry out the repair and maintenance work as required. Note that the cost of maintenance work is estimated at 2% of the total replacement cost. The net present value savings from the operating cost are $23,709 for an initial investment in repair of $10,000. This results in a SIR of $23,709/10,000 of 2.4. This SIR is greater than 1, confirming the results of the LCC. The benefits of maintenance will be decreased if the prediction regarding the life expectancy without repair of 5 years is under estimated. A sensitivity analysis can be carried out to determine the variations.

Example 4

Situation:

The director of Parks and Recreation Department of the local municipality calls on a designer. The director needs to know if they should install a 20-year warranty shingle or a 30-year warranty shingle on a small recreation facility. The cost of the 20-year warranty shingle material is $7114 and the cost of 30-year warranty shingle is $10,968. A quick calculation by the designer shows that the non-discounted cost per year of 20-year shingle v/s 30-year shingle is $356/year v/s 366/year. The 20-year shingle costs $10/year (or $200 over its 20 years) less than the 30-year shingle. For this small amount the owner would rather go with the 30-year shingle. The designer is asked to determine if discounting at a rate of 10% and assuming a study period of 30 year makes any substantial difference.

Solution:

Steps 1 to 5 have been completed in the above situation. The next step is to discount future cash flow streams. The cash flow streams for the two alternatives are shown in a cash flow diagram, Figures 4A and 4B. The BLCC program version 4.2 was used to complete step 5 and the results obtained are shown in Table 4.

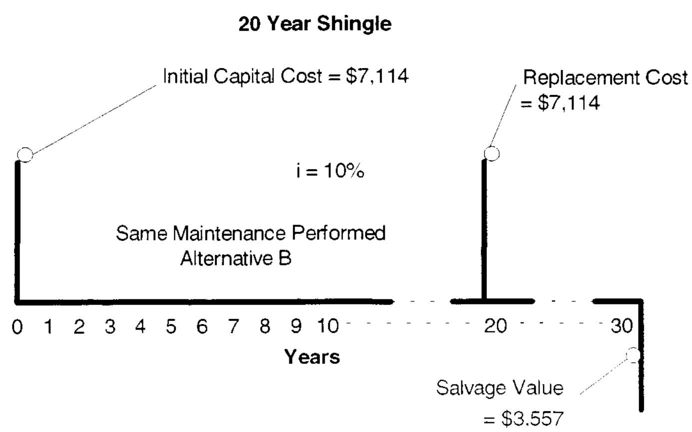


Figure 4A - Cash Flow. Example 4. Alternative A

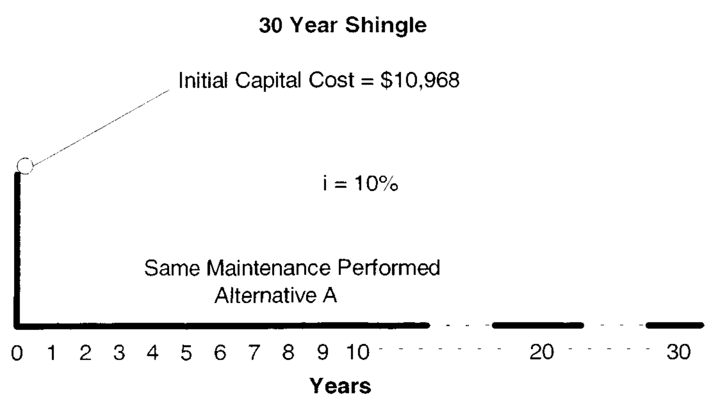


Figure 4B - Cash Flow, Example 4, Alternative B

Cost Category	Alternative A 20 Year Shingle	Alternative B 30 Year Shingle	Cost B - Cost A
Initial Capital Cost	$7.114	$10,968	$3,854
Present Value of operating costs	$0	$0	$0
Present Value of replacement costs	$1,057	$0	($1,057)
Present Value of salvage	($204)	$0	$204
Sub-Total of PV of costs and salvage	$854	$0	($854)
Total Life Cycle Cost	$7,968	$10,968	$3,000

Table 4 - Cost Summary, Example 4

The above example shows that the LCC of the 20-year shingle is lower by $3,000 or 37% then the LCC of 30-year shingle. Based on the assumptions made the 20-year shingle would be more cost-effective. The lowering of the discount rate will lower the savings and vice-versa. Even for a discount rate of 5% the 20-year shingle will be shown to have a lower cost. There are no other uncertainties that can practically impact the above decision.

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INTERNET RESOURCES

NRCC/IRC, Buildings and Life Cycle Costing, Canadian Building Digest 212, http://www.nrc.ca/irc/cbd/cbd212e.html

NIST/BFRL, Life Cycle Costing Workshop Student Manual, http://www.bfrl.nist.gov/oae/publications/nistirs/5165.html

NIST/BFRL, Life Cycle Costing Manual for Federal Energy Management Program, http://fire.nist.gov/bfrlpubs/build96/art121.html

NIST/BFRL, Multiattribute Decision Analysis, http://fire.nist.gov/bfrlpubs/build95/art066.html

National Resources Canada, Commercial Building Investment Program, Model National Energy Codes and Life Cycle Costing, http://pebc.rncan.gc.ca/whatisthemnecb/index_e.html#life

FEMP, Analytical Software Tools, Includes a link to BLCC computer program, http://www.eren.doe.gov/femp/techassist/softwaretools/softwaretools.html

EREN/DOE, BEES Introduction and Link to Software, http://www.eren.doe.gov/buildings/tools_directory/software/bees.htm