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Equivalent Annualized Cost Evaluation for Energy-Efficient Building Component Evaluation

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ABSTRACT

The use of levelized annual payment calculated by life-cycle cost analysis has been used in a project study that includes a variety of design choices. The advantage of this method is in the evaluation by the owner of both the initial costing--which relates to initial financing possibilities--and the levelized annual payment--which relates to economic optimization--for the activity. A case study is presented.

INTRODUCTION

Life-cycle costing is a method of financial analysis that considers all present and anticipated future costs of a proposed or actual project. The future costs are included and adjusted in amount according to the estimated time value of money. This cumulative "present value/cost" information is then transformed into an equivalent levelized annual cost for the project.

The method is particularly well-suited for comparing alternate designs, energy systems, and project life-times from a financial point of view. The effect of the time value of money as reflected in the general inflation rate and the discount rate is illustrated in Fig. 1. The value of a future cost in present value is projected to a future cost based on the general inflation rate. The present worth of that future cost is then determined from the use of the discount rate. Thus, all costs are compared on a present worth basis.

After the present worth of all future costs has been determined, an equivalent levelized annual cost is determined. The relationship of total costs and equivalent levelized annual costs is illustrated in Fig. 2.

Until recent years, the initial costs were the primary function in building system economic considerations. With the advent of increased energy prices, the energy costs for building systems operations has escalated to be of the same order of magnitude as the mortgage payments connected with the initial costs of the system.

Taxes have also become a significant element in the net cost of operations. Income taxes, property taxes, and tax credits for energy conservation where applicable are worthy of consideration in the total project financial analysis.

For the purpose of this discussion, it is assumed that lump sum initial costs for the life-cycle costing analysis will be available. In the design of a project, many variables are involved and all should be included in the initial cost for the particular project.

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All costs being considered will be discussed in detail here, but not necessarily in order of importance. Many textbooks on the general subject of engineering economics provide the equations for the tabular data for factors used in the calculations. The equation form is readily executable on a microcomputer and the equations presented below were taken from Newman[1] or modified for the cash-flow presentation.

MATHEMATICAL ANALYSIS FOR LIFE-CYCLE COSTING FOR SYSTEMS

Mortgage Payments

The mortgage payments consist of the payments of principal and interest on the building system. Assuming that a loan can be obtained at the market mortgage rate (i_m)--assumed to be constant--for a fixed period of time (T_L) with the interest charged on the unpaid balance of the loan at the beginning of the payment period, the amount of a level payment--principal plus interest--may be calculated by

$$C1_k = I \times CRF\ (i_m,\ T_L) \tag{1}$$

and the capital recovery factor is calculated by

$$CRF(i_m,\ T_L) = \frac{i_m(1 + i_m)^{T_L}}{[(1 + i_m)^{T_L} - 1]} \tag{2}$$

Noting that $p = I \times CRF(i_m,\ T_L)$, each payment--p--consists of payment of interest--$B \times i_m$--and principal--$(p - Bxi_m)$, where B is the balance due at the beginning of the payment period.

Interest Paid

The interest paid at the end of each period may be calculated from the equation

$$C2 = C1 \times [1 - \frac{1}{(1 + i_m)^{(T_L + 1 - k)}}] \tag{3}$$

as a matter of information and will be used in the calculation of income tax savings.

Energy Costs

The estimated energy consumption rate for the various systems should be determined from actual use or from an energy-consumption estimate based on operating conditions. It is assumed that the energy-consumption rate can be determined for each of the projects being compared by life-cycle costing.

The energy escalation rate--(i_e)--may be different than the general inflation rate and the market mortgage rate. The energy cost per period may be projected by

$$C3_k = \text{projected energy costs in period } k$$

$$C3_k = EC1 \times (1 + i_e)^{(k - 1)} \tag{4}$$

where

k may vary from 1 up to the total number of period being considered, T_s.

Miscellaneous Costs

To allow for maintenance costs, anticipated repair costs, and other irregular expense costs, the following equation is used to determine the effect of miscellaneous costs.

$$\begin{aligned} C4_k &= \text{miscellaneous costs for period } k \\ &= (\text{recurring costs at first period prices}) \\ &\quad + [\text{non-recurring specific costs for period} \\ &\quad\quad k \text{ (based on first period costing)}] \\ &\quad \times (1 + i_g)^{(k - 1)} \end{aligned} \tag{5}$$

Property Tax

The property tax on the building system is assumed to be constant. This may need to be adjustable because of the uncertainties involved in the property tax system. Any special tax considerations for alternative energy systems may be accommodated in the following equation:

$$C5 = AV \times RP \tag{6}$$

Depreciation Deduction Allowance

In the determination of income taxes, a depreciation is allowed as a deduction on the system. Four options based on other business and financial considerations are presented. It is assumed that one of these four options will be appropriate to most business situations.

1. No depreciation

$$C6_k = 0 \tag{7}$$

2. Straight-line depreciation

$$C6_k = \frac{(IC - SV)}{T_s} \tag{8}$$

3. Sum of years digits method

$$C6_k = \frac{2(T_s - k + 1)}{T_s(T_s + 1)} \times (IC - SV) \tag{9}$$

4. Declining balance method

$$C6_k = IC \times \left(\frac{SV}{IC}\right)^{(k/T_s)} \times \left[1 - \left(\frac{SV}{IC}\right)^{(1/T_s)}\right] \tag{10}$$

Income Tax Savings

Calculation of savings for income tax relief may be made based on interest paid, property taxes, and other allowable deductions for residences or businesses. Two options based on the assumption that the building systems of interest will be either residential or business are presented.

$$C7_{k_r} = (C2_k + C5_k) \times (RIN) \tag{11}$$

$$C7_{k_b} = (C2_k + C3_k + C4_k + C5_k + C6_k) \times (RIN) \tag{12}$$

Income Tax Credits

Income tax credits for business equipment investment and for certain energy-conservation measures are generally made available to the business or residence owner at the end of the tax year (or shortly thereafter) in which the expense is incurred. This generally may be calculated as

$$C10 = (IC \times RIV)$$

$$C11 = (EEC \times REC)$$

$$C12 = (SSC \times RSS)$$

If either C11 or C12 is greater than the maximum allowable, then use the maximum allowable tax credit--ECM or SSM, respectively, for C11 or C12. Finally,

$$C9 = C10 + C11 + C12 \tag{13}$$

Total Net Costs for Each Period

The total net costs for each period are:

Mortgage Payment + Energy Costs + Miscellaneous Costs

+ Property Tax - (Income Tax Savings) - (Income Tax Credits)

or

$$C8_{k_r} + C1_k + C3_k + C4_k + C5_k - C7_{k_r} - C9_k \tag{14}$$

for residential or

$$C8_{k_b} = C1_k + C3_k + C4_k + C5_k - C7_{k_b} - C9_k \tag{15}$$

for businesses.

Cumulative Present Value of Net Costs for the Building System Project

For the purpose of making a logical comparison of the costs involved with several possible project designs, all future costs are translated back to a present worth value by

$$PW = \sum_{k=1}^{T_s} C8_k \times \left(\frac{1}{1 + i_d}\right)^k \tag{16}$$

where

i_d is the discount rate and is defined as the best expected return on an alternate investment opportunity.

For example, if the system project were optional and an investment opportunity that would provide a rate of return of i_d on the invested funds existed, that rate of return would be used.

The Equivalent Levelized Period Costs

The equivalent levelized period cost is calculated from the equation

$$A = PW \times CRF(i_d, T_s) \tag{17}$$

where

$$CRF(i_d, T_s) = \frac{i_d(1 + i_d)^{T_s}}{[(1 + i_d)^{T_s} - 1]} \tag{18}$$

Example of Life-Cycle Costing for a System

A computer program has been written to execute the system of equations presented here. The input data required to execute the program consists of:

1. Number of alternates
2. Type of depreciation selected
3. Discount rate
4. Market mortgage rate
5. General inflation rate
6. Energy inflation rate
7. Income tax rate
8. Tax credit rate--conservation
9. Maximum tax credit--conservation
10. Tax credit rate--solar system
11. Maximum tax credit--solar system
12. Descriptive names of system alternates
13. Total initial project cost
14. Energy conservation measures costs
15. Solar system costs
16. Lifetime of system (number of periods)

17. Loan period

18. Salvage value of system

19. Assessed value of system (for property taxes)

20. Property tax rate

21. Investment tax credit rate

22. Energy cost in first period

23. Annual Miscellaneous cost (recurring)

24. Number of years in which nonrecurring miscellaneous exprnese occur (year and amount of each)

ENERGY USE PREDICTIONS

Many computer programs are available for building energy-use calculations--e.g., BLAST, DOE 2.1, TRNSYS. A compilation of the availability of these programs has been prepared by the Solar Energy Research Institute.[2]

For work in the schematic stages of a project, it may be sufficiently accurate to use more approximate analysis programs, such as those based on methods that use BIN-DATA,[3] with some approximations for the air-conditioning requirements.

The comparison from one building system to another yields more accurate information than the approximate total results would because the effects of the components are probably better known--except perhaps the infiltration values for certain components--than the overall operational characteristics of the building and occupant-use schedules.

There are also several commercially available programs that utilize a modified BIN-DATA method. The energy-consumption data predicted for the case study presented here were calculated by a program prepared by the author. The algorithm for weather conditions for the air-conditioning predictions was a simple harmonic function based on the average monthly temperature and the mean temperature spread for the month, with the maximum occurring at 1500 hours, Fig. 3. Solar data[4] were also used in the solar wall panels, glazing and air-conditioning energy calculations.

Various building system configurations, energy source options, solar energy components, and daylighting were considered for a relatively small project using a pre-engineered metal building as the primary structure. Results of these predictions are discussed in the following case study.

CASE STUDY

A case study of the method of levelized annual payment cost analysis may serve to clarify the steps in the procedure for its use.

The case study presented here was for a relatively small project for an implement dealer--offices, showroom, service facility, and future expansion on the second level. The base structure was a pre-engineered metal building with optional integrated solar-collector wall panels for space heating, optional daylighting panels, and some glass for showroom display.

The annual energy consumption estimates were calculated for various conditions using the modified BIN-DATA method program written by the author. The initial-cost estimates were prepared by the project architect in collaboration with a metal building manufacturer. Current local energy prices were furnished by the architect on the project.

A computer program used these data to calculate the levelized annual costs for various building and energy system configurations as given in Tab. 1. Basic assumptions used for all of the various configurations and fuel energy sources were:

1. Area--22,500 ft^2 (2090 m^2)
2. Wall height--22 ft (6.7 m)
3. Baseline cost--$15/$ft^2$ ($161/$m^2$)
4. Solar collector and storage--$10/$ft^2$ ($107/$m^2$)
5. Weather data for Akron, OH
6. Discount rate--10%
7. Market mortgage rate--10%
8. General inflation rate--10%
9. Backup system fuel inflation rate--14%
10. Income tax rate--30%
11. Tax credit for solar system--40%
12. Tax credit for energy conservation--15%
13. Maximum tax credit for solar--$12,000
14. Maximum tax credit for conservation--$300
15. Straight-line depreciation
16. Property tax rate--2%
17. Assessed value--25% of initial costs
18. Investment tax credit rate--10%
19. Electricity costs--$0.035/kWh ($9.73/GJ)
20. LP Gas--$1.00/gal ($0.264/liter)
21. Oil--$1.00/gal ($0.264/liter)
22. Current salvage value--10% of initial costs
23. Compressors replaced after 10 years
24. Furnaces replaced after 15 years
25. Solar collector glazing replaced after 15 years.

An example of the cash flow for a particular configuration (number 3 in Tab. 1) is presented as Tab. 2. The project initial costs, expected cash flows, and levelized annual costs are then readily available for review with the client.

DISCUSSION OF RESULTS

The results of the method of levelized annual costs, a special type of life-cycle costing, gives an annual equivalent cost value for various building designs, energy sources, and financial arrangements. This cost value may be used as the predicted minimum-cost option selector.

The method also may be used to prepare a predicted cash flow for a proposed project for use in negotiations with the potential owner.

CONCLUSIONS

The levelized annual cost method provides for a realistic predictive and readily understandable method for life-cycle costing analysis.

The approximate energy methods of analysis such as those based on a modified BIN-DATA method are sufficiently accurate for comparative evaluations.

The levelized annual cost method can be readily implemented on a microcomputer and is readily adaptable for small as well as large projects.

NOMENCLATURE

Symbol	Description	Units
A	Equivalent levelized period costs	$/period
AV	Assessed value of the project	$
B	Balance at the beginning of payment period	$
C	Arbitrary constant	-
C1	Amount of payment	$
C2	Interest paid	$
C3	Energy costs	$
C4	Miscellaneous costs	$
C5	Property tax	$
C6	Depreciation deduction allowance	$
C7	Income tax savings	$
C8	Total net costs	$
C9	Income tax credits	$
C10	Investment tax credit	$
C11	Energy-conservation tax credit	$
C12	Solar system tax credit	$
CRF	Cost recovery factor	-
EC1	Energy costs for the first period	$
ECC	Energy conservation project costs	$
ECM	Maximum energy conservation tax credit	$
I	Amount of initial loan	$
i	Interest rate	(1/period)
IC	Initial cost	$
p	Payment amount	$
PW	Present worth	$

Symbol	Description	Units
RP	Property tax rate	(1 period)
RIN	Income tax rate	(1 period)
RIV	Investment tax credit rate	fraction
REC	Energy conservation tax credit rate	fraction
RSS	Solar system tax credit rate	$
SCM	Maximum solar system tax credit	$
SSC	Solar system cost	$
SV	Salvage value	$
T	Time involved	No. periods
Subscripts		
b	Business facility	
d	Discount (rate of discount)	
e	Energy (rate of inflation)	
g	General (rate of inflation)	
k	Number of periods being considered	
m	Mortgage (or money)	
r	Residential	
L	Length of the mortgage	
s	Life of the project	
T	Total	

REFERENCES

1. Donald G. Newman, Engineering Economic Analysis (San Jose: Engineering Press, Inc., 1980), p. 63.

2. Doug Nordhas, Editor, "Analysis Methods for Solar Heating and Cooling Applications: Passive and Active Systems," 3rd edition (Golden, CO: Solar Energy Research Institute, 1980), p. 6.

3. U. S., Departments of the Air Force, the Army, and the Navy, "Facility Design and Planning--Engineering Weather Data" (Washington, DC: AFM 88-29, Chapter 3, 1978) (Also Army: TM-5-785; Navy: , NAVFAC, p. 89).

4. ASHRAE Handbook--1977 Fundamentals Volume, Chapters 21-26.

ACKNOWLEDGMENTS

Several contributions were made toward the work presented in this paper. The computer program for the life-cycle costing was written by Ali Jalalzadehzar. The programs for energy requirements and the costs were run on the IBM computer at Gulf States Manufacturers, Inc., of Starkville, MS. The architectural firm was Combs Architects of Richmond, IN. These contributions were appreciated by the author.

TABLE 1

Summary of Building Options and Comparative Costs

Building Configuration	Insulation R-Value Walls	Insulation R-Value Ceiling	Type of Auxiliary Heating	Solar Collector Area	Initial Costs	First Year Heating Energy Costs	Levelized Annual Costs
Units	ft^2F/Btu (m^2K/KJ)	ft^2F/Btu (m^2K/KJ)	-	ft^2 (m^2)	$	$	$
1	8 (.391)	13 (.636)	WBHP*	0	403,470	3,252	37,957
2	12 (.587)	18 (.881)	WBHP	0	407,500	2,596	36,459
3	12 (.587)	18 (.881)	WBHP	4500 (418)	452,500	1,602	36,450
4	8 (.391)	13 (.636)	WBHP	3375 (314)	437,220	2,364	37,570
5	8 (.391)	13 (.636)	WBHP	4500 (418)	448,420	2,156	38,254
6	8 (.391)	13 (.636)	WBHP	5625 (523)	459,720	1,970	38,946
7	8 (.391)	13 (.636)	LP gas	0	364,500	4,760	38,133
8	8 (.391)	13 (.636)	Oil	0	364,500	10,984	51,588
9	12 (.587)	18 (.881)	ER**	4500 (418)	409,500	4,150	38,395
10	12 (.587)	18 (.881)	ER	0	364,500	7,624	43,763

*WBHP--Water-based heat pump

**ER--Electric Resistance

TABLE 2

Typical Computer Output for Cash Flows for a Building System

System Name: HAIS (No. 3 in Table 1)

Year	Mortgage Payment	Interest Paid	Fuel Cost	Misc. Cost	Property Tax	Depreciation Deduction	Income Tax Saving	Total Cost
1	73642.50	45249.97	1602.00	1200.00	2240.00	20375.00	21200.07	-65.62
2	73642.50	42410.74	1826.28	1320.00	2240.00	20375.00	20451.59	58577.03
3	73642.50	39287.58	2081.96	1452.00	2240.00	20375.00	19630.95	59785.36
4	73642.50	35852.11	2373.43	1597.20	2240.00	20375.00	18731.31	61121.69
5	73642.50	32073.09	2705.71	1756.71	2240.00	20375.00	17745.21	62599.79
6	73642.50	27916.16	3084.50	1932.61	2240.00	20375.00	16664.48	64235.02
7	73642.50	23343.58	3516.33	2125.87	2240.00	20375.00	15480.23	66044.31
8	73642.50	18313.70	4008.62	2338.45	2240.00	20375.00	14182.72	68046.69
9	73642.50	12780.88	4569.82	2572.30	2240.00	20375.00	12761.39	70263.06
10	73642.50	6694.74	5209.59	7545.39	2240.00	20375.00	12619.41	76017.94
11	0.00	0.00	5938.93	3112.47	2240.00	20375.00	9499.92	1791.48
12	0.00	0.00	6770.37	3423.72	2240.00	20375.00	9842.72	2591.36
13	0.00	0.00	7718.22	3766.09	2240.00	20375.00	10229.79	3494.52
14	0.00	0.00	8798.76	4142.69	2240.00	20375.00	10666.93	4514.52
15	0.00	0.00	10030.59	42531.63	2240.00	20375.00	22553.15	32249.07
16	0.00	0.00	11434.86	5012.65	2240.00	20375.00	11718.75	6968.76
17	0.00	0.00	13035.74	5513.91	2240.00	20375.00	12349.39	8440.26
18	0.00	0.00	14860.73	6065.30	2240.00	20375.00	13062.30	10103.72
19	0.00	0.00	16941.21	6671.82	2240.00	20375.00	13868.41	11984.65
20	0.00	0.00	19512.98	7339.01	2240.00	20375.00	14780.09	-288621.94

**Note that all of the cash flows in this table are in terms of inflated dollars.

Present worth of costs: $310,225.00

Equivalent annual cost: $ 36,450.00

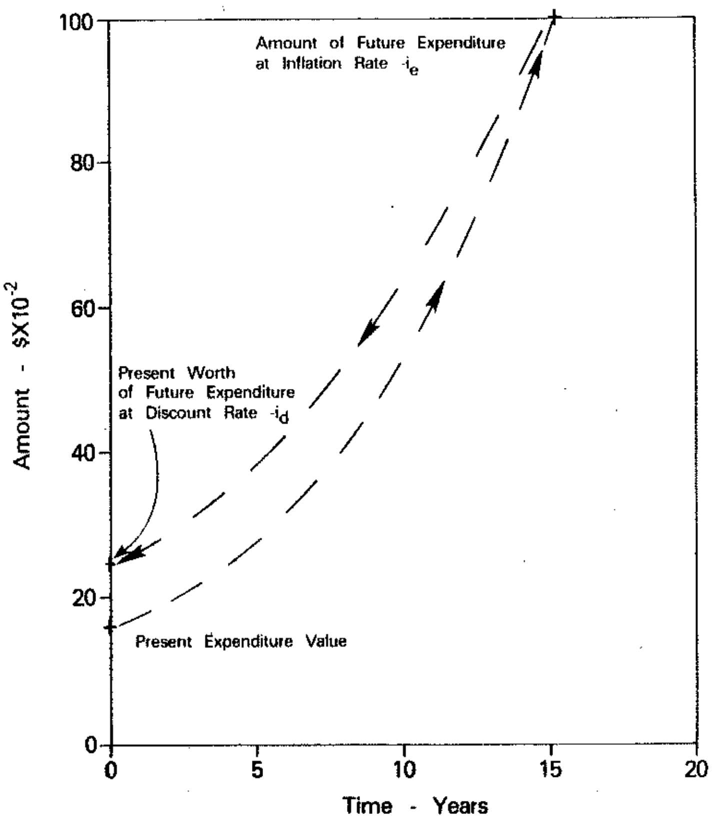

Figure 1. The effects of the Energy Inflation Rate and the Discount Rate on the present worth of a future expenditure

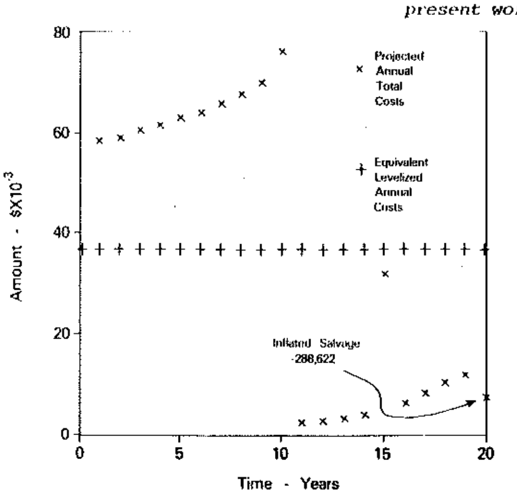

Figure 2. The relationship between Total Costs and Equivalent Levelized Annual Cost

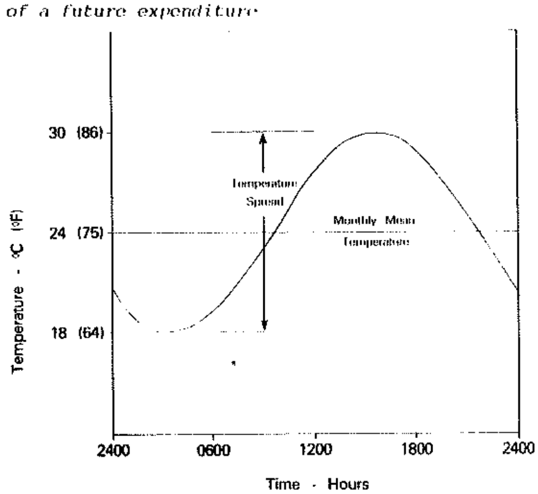

Figure 3. The Diurnal Temperature Variation Algorithm based on monthly BIN-DATA for air conditioning calculations

Discussion

R. McIntire, President, DAE Engineering, Logan, UT: Has it been used on a real building?

Bouchillon: The case study presented in the paper was for a real project under consideration by an owner, his architect/constructor, and a metal building manufacturer.

J.T. Norris, Div. Manager, Lilco, Mineola, NY: Was any consideration given to the cooling load (i.e., air conditioning) in the design?

C.W. Bouchillon: The cooling load--or costs of air conditioning--may easily be included in the calculations. In the case study presented, air conditioning was not considered as an option.