

## GENERAL

Life-cycle costing (LCC) is a method for evaluating all relevant costs over time of alternative building designs, systems, components, materials, or practices. The LCC method takes into account first costs, including the cost of planning, design, purchase, and installation; future costs, including costs of fuel, operation, maintenance, repair, and replacement; and any resale or salvage value recovered during or at the end of the time period examined.

## TIME ADJUSTMENTS

Adjustments to place all dollar values on a comparable time basis are necessary for the valid assessment of a project's life-cycle costs. Time adjustments are necessary because receiving or expending a dollar in the future is not the same as receiving or expending a dollar today. Currency's purchasing power may fall over time because of inflation, and money in hand may be invested productively to earn a return over time, apart from inflation. Because of inflation and the productive earning potential of resources in hand, investors usually prefer to delay payments of costs or debts and to hasten receipts. The adjustment for time can be accomplished by converting all costs and resale or salvage values to "present values," as though they were all to be incurred today, or to "annual values," as though they were all spread out over a given time in even, annual installments. This time adjustment, often called "discounting cash flows," is accomplished by using "discount formulas" or by multiplying dollar amounts by special "discount factors" calculated from the formulas. The most frequently used discount formulas for evaluating building projects are described below. The following notation is used:

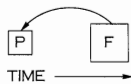
P = present value  
 F = future value  
 A = annual value  
 $A_0$  = initial value of a periodic amount  
 D = discount rate  
 N = number of periods  
 E = price escalation rate

D is the minimum rate of return the investor is willing to accept and is based on the yield available on the next best investment opportunity of comparable risk. The values of D, F, and E specified in the discount operations below can be expressed in either of two ways: including or excluding projected general price inflation/deflation. It is essential, however, that they all be treated consistently within a given LCC analysis. If general price inflation/deflation is included, the analysis is said to be in "current dollars"; if it is excluded, the analysis is said to be in "constant dollars." Both approaches result in the same LCC results.

## SINGLE PRESENT WORTH

The single present worth (SPW) formula is used to find the present value of a future amount, such as the value today of a future replacement cost.

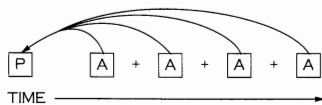
$$SPW \text{ (single present worth)} \quad P = F(1 + D)^{-N}$$



## UNIFORM PRESENT WORTH

The uniform present worth (UPW) formula is used to find the present value of a series of uniform annual amounts, such as the value today of the costs of future yearly routine maintenance.

$$UPW \text{ (uniform present worth)} \quad P = A \left[ \frac{(1 + D)^N - 1}{D(1 + D)^N} \right]$$



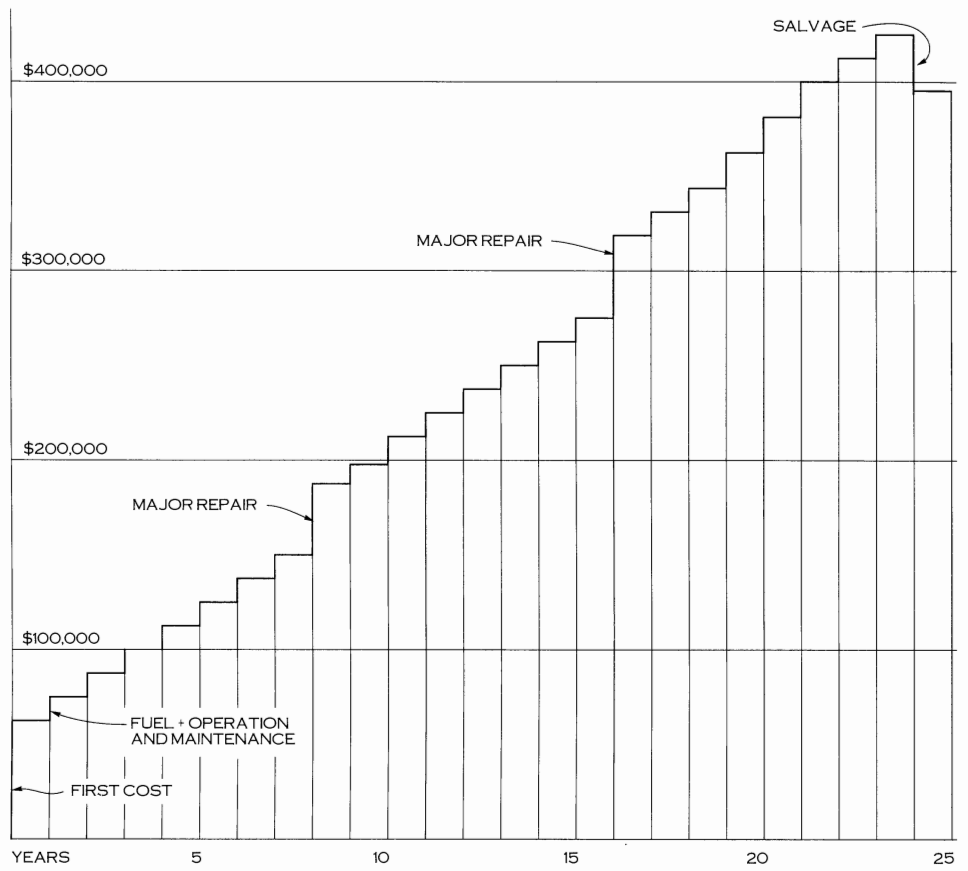
## MODIFIED UNIFORM PRESENT WORTH

A modified version of the uniform present worth formula (here designated UPW\*) is used to find the present value of an initial value of a periodic amount ( $A_0$ ) escalating at a constant annual rate (E), such as the value today of future yearly energy costs, when energy prices are expected to escalate at a given rate.

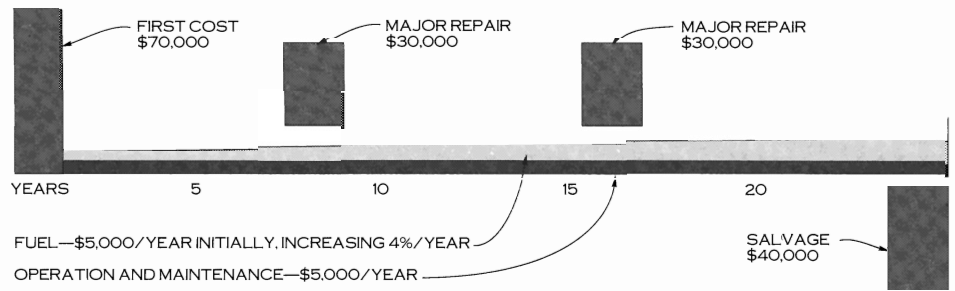
UPW\* (uniform present worth-modified)

$$P = A_0 \left[ \frac{1 + E}{D - E} \right] \left[ 1 - \left( \frac{1 + E}{1 + D} \right)^N \right]$$

Harold E. Marshall and Rosalie Ruegg, economists; Porter Driscoll, AIA, Architect, National Institute of Standards and Technology



## CUMULATIVE COSTS

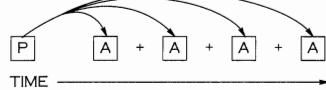


## YEARLY COSTS

### UNIFORM CAPITAL RECOVERY

The uniform capital recovery (UCR) formula is used to find the annual value of a present value amount. It can be used to amortize a loan, i.e., to determine how much it would be necessary to pay each year in order to pay off a loan made today at a given rate of interest for a given period of time.

$$UCR \text{ (uniform capital recovery)} \quad A = P \left[ \frac{D(1 + D)^N}{(1 + D)^N - 1} \right]$$



### NOTE

The discount factors for each of these discounting formulas have been precalculated for a range of discount rates and time periods and put into tables to facilitate their use. These tables can be found in most engineering economics textbooks. A table of discount factors for a 10% discount rate is shown opposite.

### LIFE-CYCLE COST FORMULA

To find the total life-cycle cost of a project, sum the present values (or, alternatively, the annual values) of each kind of cost and subtract the present values (or annual values) of any positive cash flows such as resale values. Thus, where all dollar amounts are adjusted by discounting to either

present values or annual values, the following formula applies:

$$\text{Life-cycle cost} = \text{first costs} + \text{maintenance and repair} + \text{energy} + \text{replacement} - \text{salvage value}$$

### APPLICATIONS

Alternative projects may be compared by computing the life-cycle costs for each project using the formula above and seeing which is lower.

The LCC method can be applied to many different kinds of building problems when the focus is on determining the least-cost alternative for achieving a given level of performance.

For example, it can be used to compare the long-run costs of two building designs; to determine the expected dollar savings of retrofitting a building for energy conservation or the least expensive way of reaching a targeted energy budget for a building; to select the most economical floor coverings and furnishings; or to determine the optimal size of a solar energy system.

In addition to the life-cycle formula shown above, there are other closely related methods of combining present or annual values to measure a project's economic performance over time, such as net benefits or net savings, benefit-to-cost or savings-to-investment ratio, internal rate of return or overall rate of return; and discounted time to payback methods.

**SAMPLE LCC PROBLEM**

Determine for a public office building the present value of costs that will occur during the life of a component so it can be compared with the value of costs for an alternative component that serves the same purpose.

**ASSUMPTIONS**

Component life (for both)	25 years
Discount rate	10%
Fuel price increases in excess of inflation (i.e., excluding inflation)	4%
First cost of component	\$70,000
Repairs to component at 8th and 16th years (constant dollars)	\$30,000/repair
Operations and maintenance (constant dollars)	\$5,000/year
Annual cost of fuel at onset	\$5,000

**NOTE**

When financing costs and tax effects are relevant, they should be incorporated into LCC analysis. For this public building they are not relevant.

**SOLUTION**

1. Calculate present value of equipment by converting all equipment costs (first cost, two major repair costs, and salvage value) to present values and combining them. (Since the first cost occurs in the present, no change is made to the \$70,000 sum.)

The first major repair, estimated to occur 8 years in the future, is discounted at the rate of 10% back to the present using the SPW factor (see Discount Factor Chart, column 2) for 8 years at 10%, 0.4665. Therefore,  $PV = \$30,000 \times 0.4665 = \$13,995$ .

The second major repair is discounted 16 years back to the present in a similar manner. The SPW factor for 16 years at 10% = 0.2176. Therefore,  $PV = \$30,000 \times 0.2176 = \$6,528$ . These two present values are added to the first cost of the component.

The \$40,000 to be realized from salvage at the end of the 25-year period is discounted back to the present in the same manner. The SPW factor for 25 years, at 10% = 0.0923. Therefore,  $PV = \$40,000 \times 0.0923 = \$3,692$ . Since this sum is income, not expense, it must be subtracted from the sum of the other present values as indicated.

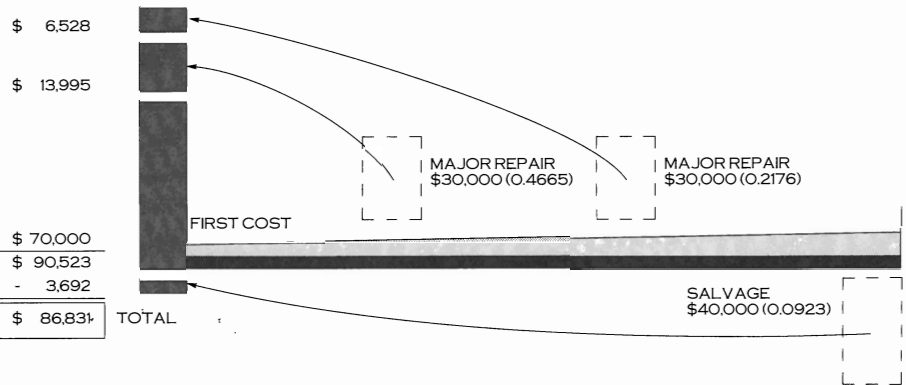
Thus, the present value of equipment is determined to be \$86,831.

2. Establish present value of operation and maintenance costs and fuel costs. Operation and maintenance costs are estimated to be equal amounts that occur yearly during the component life and are converted to present value using the UPW factor (column 3) for 25 years at 10%, 9.0770. Therefore  $PV = \$5,000 \times 9.0770 = \$45,385$ . Annual fuel costs are estimated to be \$5,000 initially and are projected to increase at the rate of 4% per year higher than general price inflation. These costs are converted to present value using the modified UPW\* factor (column 4) for 25 years at 10%, 13.0686. Therefore,  $PV = \$5,000 \times 13.0686 = \$65,343$ . These two present values are added to the present value of equipment costs as shown in the Total Present Value chart.

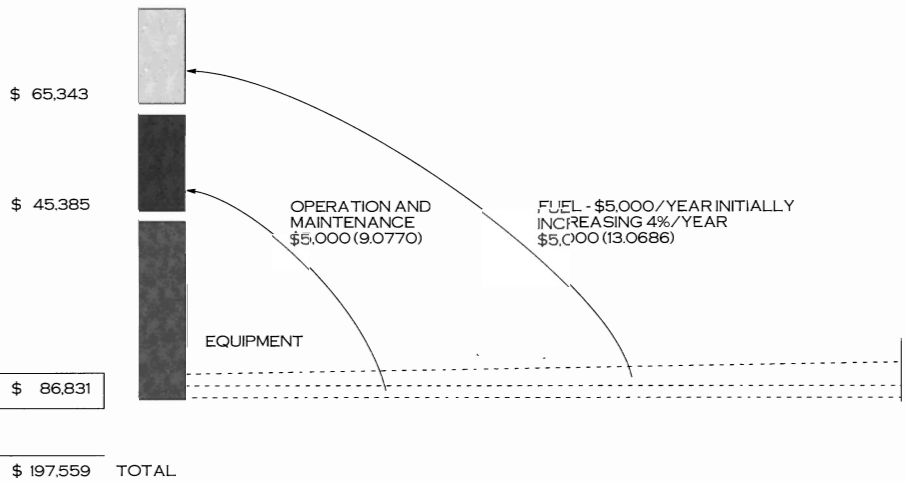
3. Total life-cycle cost in present value dollars is the sum of the present value of equipment, operation and maintenance, and fuel costs, which equals \$197,559. The present value of equipment, operation and maintenance, and fuel costs of other components that serve the same purpose can be computed over the same period of time and compared to these figures to determine the best economic value.

**REFERENCES**

- Rosalie T. Ruegg and Harold E. Marshall, *Building Economics: Theory and Practice* (New York: Van Nostrand, Reinhold, 1990).
- Harold E. Marshall and Rosalie T. Ruegg, "Life-cycle Costing Guide for Energy Conservation in Buildings" in *Energy Conservation through Building Design*, ed. Donald Watson (New York: McGraw-Hill, 1979).
- "Simplified Energy Design Economics," NBS special publication 544, Center for Building Technology, National Bureau of Standards, Washington, D.C., 1980.



**PRESENT VALUE OF EQUIPMENT**



**TOTAL PRESENT VALUE**

**DISCOUNT FACTORS (BASED ON 10% DISCOUNT RATE)**

1. YEARS	2. SPW	3. UPW	4. UPW* (4% PRICE ESCALATION)	5. UCR
1	0.9091	0.909	0.9455	1.100 00
2	0.8264	1.736	1.8393	0.576 19
3	0.7513	2.487	2.6844	0.402 11
4	0.6830	3.170	3.4834	0.315 47
5	0.6209	3.791	4.2388	0.263 80
6	0.5645	4.355	4.9531	0.229 61
7	0.5132	4.868	5.6284	0.205 41
8	0.4665	5.335	6.2669	0.187 44
9	0.4241	5.759	6.8705	0.173 64
10	0.3855	6.144	7.4411	0.162 75
11	0.3505	6.495	7.9807	0.153 96
12	0.3186	6.814	8.4909	0.146 76
13	0.2897	7.103	8.9733	0.140 78
14	0.2633	7.367	9.4293	0.135 75
15	0.2394	7.606	9.8604	0.131 47
16	0.2176	7.824	10.2680	0.127 82
17	0.1978	8.022	10.6535	0.124 66
18	0.1799	8.201	11.0177	0.121 93
19	0.1635	8.365	11.3622	0.119 55
20	0.1486	8.514	11.6878	0.117 46
21	0.1351	8.649	11.9957	0.115 62
22	0.1228	8.772	12.2870	0.114 01
23	0.1117	8.883	12.5623	0.112 57
24	0.1015	8.985	12.8225	0.111 30
25	0.0923	9.077	13.0686	0.110 17

# LIFE CYCLE OF COMMON BUILDING MATERIALS

	ALUMINUM	STEEL	PARTICLEBOARD
Raw materials acquisition and preparation	<ul style="list-style-type: none"> <li>Manufacturing depletes the mineral bauxite, a finite resource (only 125 years remain at the current rate of consumption).</li> <li>Bauxite strip mining causes loss of large tracts of land, including some loss of tropical forests and habitats.</li> <li>Reclamation of strip mines reduces long-term effects but some species may be lost.</li> <li>Other raw materials consumed during acquisition include lime, caustic, soda, crude oil, and coal.</li> <li>Degradation of ground and surface water and air may occur from mining.</li> </ul>	<ul style="list-style-type: none"> <li>Manufacturing depletes supplies of iron ore, limestone, and coal, all finite resources.</li> <li>Processing of coal into coke produces toxic air pollutants.</li> <li>Deep pit mining causes loss of virgin forests and lands; land reclamation may reduce long term effects</li> <li>Degradation of ground and surface water and air may occur from mining</li> </ul>	<ul style="list-style-type: none"> <li>Approximately 90% of the wood component of this product comes from sawmill waste; if managed, sustainable and renewable wood cellulose sources are used, natural resource depletion is eliminated; if sawmill waste from old growth trees is used, those forests and habitats will be lost.</li> <li>Size of wood chips varies from 25mm to particles as fine as flour.</li> <li>98% of the resin binder in particleboard is urea formaldehyde (urea is derived from petroleum and formaldehyde from natural gas); 1.6% of the resin used is phenol formaldehyde (phenol is derived from coal tar and petroleum).</li> </ul>
Raw materials processing and manufacturing	<ul style="list-style-type: none"> <li>Smelting and ingot casting is energy intensive.</li> <li>Different finishes vary in their environmental burdens: anodizing and powdered paint coatings have few negative environmental effects, while electroplating and related finishes are highly polluting.</li> </ul>	<ul style="list-style-type: none"> <li>Raw materials and resources used in processing include nickel, manganese, chromium, lubricating oils, solvents, acids, and alkalies.</li> <li>Iron is produced from iron ore, coke, and lime, which is heated in blast furnaces.</li> <li>Steel is made from iron by either the basic oxygen furnace method, using 30% scrap, or the electric furnace method, using all scrap steel and iron.</li> </ul>	<ul style="list-style-type: none"> <li>Gaseous formaldehyde emissions occur in drying and mat pressing stages of processing.</li> </ul>
Product packaging and final packaging	<ul style="list-style-type: none"> <li>Packaging of materials varies; choose products that use minimal packaging or packaging made of recycled materials and/or that is itself recyclable.</li> </ul>		
Product distribution	<ul style="list-style-type: none"> <li>Distribution varies; choose products made and/or distributed from a place as close to the building site as possible.</li> </ul>		
Product installation, use, and maintenance	<ul style="list-style-type: none"> <li>Generally a low maintenance material, depending on finish. Painted aluminum surfaces require periodic repainting; anodized finishes and powdered paint coatings require occasional cleaning.</li> </ul>	<ul style="list-style-type: none"> <li>Maintenance depends on which alloy is used (e.g., stainless steel), whether electrolytic treatment has been done (e.g., galvanized steel), and whether a coating has been applied.</li> <li>Preparation of the surface for repainting or other maintenance may require use of solvents or acids.</li> <li>Weathering steel, which forms a protective oxidized coating, is also available.</li> </ul>	<ul style="list-style-type: none"> <li>Most uses are for applications such as cabinet and furniture core stock (MDF), nonstructural floor underlayment, and manufactured home decking. Since the uses are located in protected and confined areas beneath finishes, degradation and maintenance are minimized. Nonetheless, some interior air pollution from offgassing may occur.</li> </ul>
Final disposal, reuse, or recycle	<ul style="list-style-type: none"> <li>Scrap can be recovered, recycled, and reused endlessly; use of recycled aluminum reduces total energy requirements by 90–95%, however, only 15–20% of aluminum in construction is recovered and recycled since it is "bound up" with other materials and difficult to separate.</li> <li>Final disposal causes no ill environmental effects, except ground water contamination from coatings and landfill overcrowding.</li> </ul>	<ul style="list-style-type: none"> <li>By way of magnetic separating processes, scrap is easily recovered and recycled. Recycled steel saves energy and raw materials and reduces contamination of the environment.</li> <li>Final disposal causes no ill environmental effects except groundwater contamination from coatings and landfill overcrowding; steel eventually oxidizes back into a natural state. Limited sorting of steel alloys required in recycling.</li> </ul>	<ul style="list-style-type: none"> <li>Since particleboard is usually bound tightly into assemblies with other materials and finishes such as laminates, recycling is difficult, although possible.</li> </ul>
Energy consumption totals	<ul style="list-style-type: none"> <li>The aluminum industry accounts for 1.4% of annual world energy consumption.</li> <li>Embodied energy at point-of-use for one pound of aluminum is estimated at 102,500 BTUs. Aluminum produced from recovered scrap and recycled aluminum rather than bauxite ore saves 80% of total energy consumption.</li> </ul>	<ul style="list-style-type: none"> <li>Embodied energy at point-of-use for one pound of steel is estimated at 19,200 BTUs. Processes using scrap steel and iron save energy by skipping blast furnace energy consumption.</li> </ul>	<ul style="list-style-type: none"> <li>Embodied energy at point-of-use for one pound of underlayment particleboard is estimated at 7,000 BTUs, 30-40% of which is derived from the resin adhesive.</li> <li>Energy consumed in production is mostly used for heat to dry particles, heat resins, and create steam for hot presses. Depending on the manufacturing plant, wood, gas, and oil are used for energy; however, 78% of the total energy bound up in wood products comes from the burning of wood waste.</li> </ul>
Waste generation total	<ul style="list-style-type: none"> <li>Bauxite refining yields large volumes of mud containing trace amounts of hazardous waste.</li> <li>Although most airborne emissions are contained by wet scrubbing, small amounts of carcinogenic hydrocarbons escape during smelting and forming.</li> <li>Fabrication and finishing may produce heavy metal sludges and large amounts of waste waters that require treatment with toxic chemicals.</li> <li>Solid wastes include used potliners of carbon, insulation material, fluoride, and cyanide.</li> </ul>	<ul style="list-style-type: none"> <li>Both deep pit and strip mining of iron ore, coal, and limestone yield large amounts of discarded rock and soil, resulting in erosion and contamination of water by dissolved toxic minerals. The production of one ton of steel creates 1.5 tons of waste materials.</li> <li>Mine spoils from coal mining may acidify nearby soils and water.</li> <li>Coke ovens may emit toxic sulphur dioxide fumes, carbon monoxide, and other particulate emissions; processing limestone into lime releases carbon dioxide emissions into the air.</li> <li>Liquid wastes produced by processing include lubricants, electrolytic coatings, pickling solutions, paints, and contaminated water.</li> <li>Solid wastes include by-products from the processing of iron ore, limestone, and coal.</li> </ul>	<ul style="list-style-type: none"> <li>Most solid waste from particleboard manufacturing is recovered in the mill or used as fuel; panel trim pieces and defective panels are ground up and put back into raw material stock.</li> <li>Production of resins results in waste waters that may contain toxic monomers.</li> </ul>
Conclusion for designers	<ul style="list-style-type: none"> <li>Although its embodied energy is very high, when compared pound for pound to alternative materials aluminum may be preferable as it is very strong and durable, lightweight, and readily recyclable.</li> <li>Specify aluminum products that are made fully or partially from recycled scrap.</li> <li>Consider designs that will facilitate recycling; avoid, if possible, mixed-material assemblies.</li> <li>Anodized finishes and powdered paint coatings may be the most environmentally friendly finishes.</li> <li>In applications where the uniquely advantageous characteristics of aluminum are not needed, consider low energy-consuming alternative materials that are recyclable.</li> </ul>	<ul style="list-style-type: none"> <li>Since many steel products are made totally or partially from recycled steel, steel is considered less environmentally harmful than other alternatives.</li> <li>Steel can be used very efficiently in reinforced concrete as a structural material. However, this practice usually binds the steel permanently with the concrete, making it nonrecyclable.</li> <li>Steel, regardless of coating, treatments, and alloys, can be recovered and recycled easily.</li> </ul>	<ul style="list-style-type: none"> <li>Urea formaldehyde (UF) particleboard offgasses formaldehyde into indoor air. Levels of emission are higher in spaces with high temperature and humidity levels; all emission levels decrease over time.</li> <li>Specify low-emitting, UF-bonded particleboard where practical, or consider sealing UF particleboard or using phenol formaldehyde-bonded particleboard (exterior grade plywood, etc.).</li> </ul>