CHAPTER 36

OWNING AND OPERATING COSTS

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OWNING and operating cost information for the HVAC system should be part of the investment plan of a facility. This information can be used for preparing annual budgets, managing assets, and selecting design options. Table 1 shows a representative form that summarizes these costs.

A properly engineered system must also be economical, but this is difficult to assess because of the complexities surrounding the effective management of money and the inherent difficulty of predicting future operating and maintenance expenses. Complex tax structures and the time value of money can affect the final engineering decision. This does not imply the use of either the cheapest or the most expensive system; instead, it demands an intelligent analysis of the financial objectives and requirements of the owner.

Certain tangible and intangible costs or benefits must also be considered when assessing owning and operating costs. Local codes may require highly skilled or certified operators for specific types of equipment. This could be a significant cost over the life of the system. Similarly, such intangible items as aesthetics, acoustics, comfort, safety, security, flexibility, and environmental impact may vary by location and be important to a particular building or facility.

OWNING COSTS

The following elements must be established to calculate annual owning costs: (1) initial cost, (2) analysis or study period, (3) interest or discount rate, and (4) other periodic costs such as insurance, property taxes, refurbishment, or disposal fees. Once established, these elements are coupled with operating costs to develop an economic analysis, which may be a simple payback evaluation or an in-depth analysis such as outlined in the section on Economic Analysis Techniques.

Initial Cost

Major decisions affecting annual owning and operating costs for the life of the building must generally be made before completion of contract drawings and specifications. To achieve the best performance and economics, comparisons between alternative methods of solving the engineering problems peculiar to each project should be made in the early stages of design. Oversimplified estimates can lead to substantial errors in evaluating the system.

The process of evaluation should lead to a thorough understanding of the installation costs and accessory requirements for the system(s) under consideration. Detailed lists of materials, controls, space and structural requirements, services, installation labor, and so forth can be prepared to increase the accuracy in preliminary cost estimates. A reasonable estimate of the capital cost of components may be derived from cost records of recent installations of comparable design or from quotations submitted by manufacturers and

The preparation of this chapter is assigned to TC 1.8, Owning and Operating Costs.

Table 1 Owning and Operating Cost Data and Summary

OWNING COSTS			
I.	Initial Cost of System		_______
II.	Periodic Costs		
	A. Income taxes	_______	
	B. Property taxes	_______	
	C. Insurance	_______	
	D. Rent	_______	
	E. Other periodic costs	_______	
	Total Periodic Costs		_______
III.	Replacement Cost		_______
IV.	Salvage Value		_______
	Total Owning Costs		_______
OPERATING COSTS			
V.	Annual Utility, Fuel, Water, etc., Costs		
	A. Utilities		
	1. Electricity	_______	
	2. Natural gas	_______	
	3. Water/sewer	_______	
	4. Purchased steam	_______	
	5. Purchased hot/chilled water	_______	
	B. Fuels		
	1. Propane	_______	
	2. Fuel oil	_______	
	3. Diesel	_______	
	4. Coal	_______	
	C. On-site generation of electricity	_______	
	D. Other utility, fuel, water, etc., costs	_______	
	Total		_______
VI.	Annual Maintenance Allowances/Costs		
	A. In-house labor	_______	
	B. Contracted maintenance service	_______	
	C. In-house materials	_______	
	D. Other maintenance allowances/costs	_______	
	Total		_______
VII.	Annual Administration Costs		_______
	Total Annual Operating Costs		_______
TOTAL ANNUAL OWNING AND OPERATING COSTS			_______

Table 2 Initial Cost Checklist

Energy and Fuel Service Costs
Fuel service, storage, handling, piping, and distribution costs
Electrical service entrance and distribution equipment costs
Total energy plant
Heat-Producing Equipment
Boilers and furnaces
Steam-water converters
Heat pumps or resistance heaters
Makeup air heaters
Heat-producing equipment auxiliaries
Refrigeration Equipment
Compressors, chillers, or absorption units
Cooling towers, condensers, well water supplies
Refrigeration equipment auxiliaries
Heat Distribution Equipment
Pumps, reducing valves, piping, piping insulation, etc.
Terminal units or devices
Cooling Distribution Equipment
Pumps, piping, piping insulation, condensate drains, etc.
Terminal units, mixing boxes, diffusers, grilles, etc.
Air Treatment and Distribution Equipment
Air heaters, humidifiers, dehumidifiers, filters, etc.
Fans, ducts, duct insulation, dampers, etc.
Exhaust and return systems
Heat recovery systems
System and Controls Automation
Terminal or zone controls
System program control
Alarms and indicator system
Energy management system
Building Construction and Alteration
Mechanical and electric space
Chimneys and flues
Building insulation
Solar radiation controls
Acoustical and vibration treatment
Distribution shafts, machinery foundations, furring

contractors or by consulting commercially available cost-estimating guides and software. Table 2 shows a representative checklist for initial costs.

Analysis Period

The time frame over which an economic analysis is performed greatly affects the results of the analysis. The analysis period is usually determined by specific analysis objectives, such as length of planned ownership or loan repayment period. However, as the length of time in the analysis period increases, there is a diminishing impact on net present value calculations. The chosen analysis period is often unrelated to the equipment depreciation period or service life, although these factors may be important in the analysis.

Service Life

Table 3 lists representative estimates of the service life of various system components. Service life as used here is the time during which a particular system or component remains in its original service application. Hiller (2000) discusses service life in more detail.

Estimated service life of new equipment or components of systems not listed in Table 3 may be obtained from manufacturers, associations, consortia, or governmental agencies. Because of this information's proprietary nature, the variety of criteria used in compilation, and the objectives in disseminating data, extreme care must be exercised in comparing service life from different sources. New designs, materials, and components of equipment listed in Table 3 have changed over time and may have altered those estimated service lives. Establishing equivalent comparisons of service life is important.

Replacement may be for any reason, including, but not limited to, failure, general obsolescence, reduced reliability, excessive maintenance cost, and changed system requirements due to such influences as building characteristics, energy prices, or environmental considerations. Locations in potentially corrosive environments and unique maintenance variables will affect the service life of HVAC equipment. Examples include the following:

- **Coastal and marine environments**, especially in tropical locations, are characterized by abundant sodium chloride (salt) that is carried by sea spray, mist, or fog.

  Many owners with locations throughout the United States require equipment specifications stating that HVAC equipment located along coastal waters will have corrosion-resistant materials or coatings. The design criteria for systems installed under these conditions should be carefully considered.
- **Industrial** applications provide many challenges to the HVAC designer. It is very important to know if the emissions from the industrial plant contain products of combustion from coal, fuel oils, or releases of sulfur oxides (SO_2, SO_3) and nitrogen oxides (NO_x) into the atmosphere. These gases typically accumulate and return to the ground in the form of acid rain or dew.

  Not only is it important to know the products being emitted from the industrial plant you are designing, but also the adjacent upwind or downwind facilities. HVAC system design for a plant located downwind from a paper mill will require extraordinary corrosion protection or recognition of a reduced service life of the HVAC equipment.
- **Urban** areas generally have high levels of automotive emissions as well as an abundance of combustion by-products. Both of these contain elevated sulfur oxide and nitrogen oxide concentrations.
- **Maintenance** factors also affect cooling coil life expectancy. The coils specified in Table 3 include DX, water, or steam (20 years) and electric (15 years). The HVAC designer should temper the service life expectancy of coils with a **maintenance factor**. Chilled-water coils with more than four rows and close fin spacing are virtually impossible to clean even using extraordinary cleaning methods. In order to realize the estimated service life values in Table 3, HVAC cooling coils must be maintained properly, including good filter-changing practices and good maintenance procedures. Many times coils with more than four rows are replaced with multiple coils in series with a maximum of four rows and lighter fin spacing.

Depreciation periods are usually set by federal, state, or local tax laws, which change periodically. Applicable tax laws should be consulted for more information on depreciation.

Interest or Discount Rate

Most major economic analyses consider the opportunity cost of borrowing money, inflation, and the time value of money. **Opportunity cost** of money reflects the earnings that investing (or lending) the money can produce. **Inflation** (price escalation) decreases the purchasing or investing power (value) of future money because it can buy less in the future. **Time value** of money reflects the fact that money received today is more useful than the same amount received a year from now, even with zero inflation, because the money is available earlier for reinvestment.

The cost or value of money must also be considered. When borrowing money, a percentage fee or interest rate must normally be paid. However, the interest rate may not necessarily be the correct cost of money to use in an economic analysis. Another factor, called the **discount rate**, is more commonly used to reflect the true cost of money (Refer to NIST *Handbook* 135 for detailed discussions). Discount rates used for analyses vary depending on individual investment, profit, and other opportunities. Interest rates, in contrast, tend to be more centrally fixed by lending institutions.

To minimize the confusion caused by the vague definition and variable nature of discount rates, the U.S. government has specified particular discount rates that can be used in economic analyses relating to federal expenditures. These discount rates are updated annually (Fuller and Boyles 2001; OMB 1992) but may not be appropriate for private-sector economic analyses.

Periodic Costs

Regularly or periodically recurring costs include insurance, property taxes, income taxes, rent, refurbishment expenses, disposal fees (e.g., refrigerant recycling costs), occasional major repair costs, and decommissioning expenses.

Insurance. Insurance reimburses a property owner for a financial loss so that equipment can be repaired or replaced. Insurance often indemnifies the owner from liability as well. Financial recovery may include replacing income, rents, or profits lost due to property damage.

Some of the principal factors that influence the total annual insurance premium are building size, construction materials, amount and size of mechanical equipment, geographic location, and policy deductibles. Some regulations set minimum required insurance coverages and premiums that may be charged for various forms of insurable property.

Property Taxes. Property taxes differ widely and may be collected by one or more agencies, such as state, county, or local governments or special assessment districts. Furthermore, property taxes may apply to both real (land, buildings) and personal (everything else) property. Property taxes are most often calculated as a percentage of assessed value but are also determined in other ways, such as fixed fees, license fees, registration fees, etc. Moreover, definitions of assessed value vary widely in different geographic areas. Tax experts should be consulted for applicable practices in a given area.

Income Taxes. Taxes are generally imposed in proportion to net income, after allowance for expenses, depreciation, and numerous other factors. Special tax treatment is often granted to encourage certain investments. Income tax professionals can provide up-to-date information on income tax treatments.

Other Periodic Costs. Examples of other costs include changes in regulations that require unscheduled equipment refurbishment to eliminate use of hazardous substances, and disposal costs for such substances.

Replacement Costs and Salvage Value

Replacement costs and salvage value should be evaluated when calculating the owning cost. At the end of the equipment's useful life there may be negative salvage value (i.e., removal, disposal, or decommissioning costs).

OPERATING COSTS

Operating costs are those incurred by the actual operation of the system. They include costs of fuel and electricity, wages, supplies, water, material, and maintenance parts and services. Chapter 31 of the 2001 *ASHRAE Handbook—Fundamentals* outlines how fuel and electrical requirements are estimated. Note that total energy consumption cannot generally be multiplied by a per unit energy cost to arrive at annual utility cost.

Table 3 Estimates of Service Lives of Various System Components[a]

Equipment Item	Median Years	Equipment Item	Median Years	Equipment Item	Median Years
Air conditioners		Air terminals		Air-cooled condensers	20
Window unit	10	Diffusers, grilles, and registers	27	Evaporative condensers	20
Residential single or split package	15	Induction and fan-coil units	20	Insulation	
Commercial through-the-wall	15	VAV and double-duct boxes	20	Molded	20
Water-cooled package	15	Air washers	17	Blanket	24
Heat pumps		Ductwork	30	Pumps	
Residential air-to-air	15[b]	Dampers	20	Base-mounted	20
Commercial air-to-air	15	Fans		Pipe-mounted	10
Commercial water-to-air	19	Centrifugal	25	Sump and well	10
Roof-top air conditioners		Axial	20	Condensate	15
Single-zone	15	Propeller	15	Reciprocating engines	20
Multizone	15	Ventilating roof-mounted	20	Steam turbines	30
Boilers, hot water (steam)		Coils		Electric motors	18
Steel water-tube	24 (30)	DX, water, or steam	20	Motor starters	17
Steel fire-tube	25 (25)	Electric	15	Electric transformers	30
Cast iron	35 (30)	Heat exchangers		Controls	
Electric	15	Shell-and-tube	24	Pneumatic	20
Burners	21	Reciprocating compressors	20	Electric	16
Furnaces		Package chillers		Electronic	15
Gas- or oil-fired	18	Reciprocating	20	Valve actuators	
Unit heaters		Centrifugal	23	Hydraulic	15
Gas or electric	13	Absorption	23	Pneumatic	20
Hot water or steam	20	Cooling towers		Self-contained	10
Radiant heaters		Galvanized metal	20		
Electric	10	Wood	20		
Hot water or steam	25	Ceramic	34		

Notes: 1. ASHRAE makes no claims as to the *statistical* validity of any of the data presented in this table.
2. Table lists base values that should be adjusted for local conditions (see the section on Service Life).

Source: Data obtained from a survey of the United States by ASHRAE Technical Committee TC 1.8 (Akalin 1978).
[a] See Lovvorn and Hiller (1985) and Easton Consultants (1986) for further information.
[b] Data updated by TC 1.8 in 1986.

Future energy costs used in discounted payback analyses must be carefully evaluated. Energy costs have historically escalated at a different rate than the overall inflation rate as measured by the consumer price index. To assist in life-cycle cost analysis, fuel price escalation rate forecasts, by end-use sector and fuel type, are updated annually by the National Institute of Standards and Technology, and published in the *Annual Supplement to NIST Handbook 135* (Fuller and Boyles 2001). Future natural gas prices are also forecast by the Gas Research Institute and published annually (GRI 2000). There are no published projection rates for water prices to be used in life-cycle cost analyses. Water escalation rates should be obtained from the local water utility when possible. Building designers should use energy price projections from their local utility in place of regional forecasts whenever possible, especially when evaluating alternative fuel types.

Deregulation in some areas may allow increased access to nontraditional energy providers and pricing structures; in other areas, traditional utility infrastructures and practices may prevail. The amount and profile of the energy used by the facility will also determine energy cost. Unbundling energy services (having separate contracts for the energy and for its transportation to point of use) may dictate separate agreements for each service component or may be packaged by a single provider. Contract length and price stability are factors in assessing nontraditional versus traditional energy suppliers when estimating operating costs. The degree of energy supply and system reliability and price stability considered necessary by the owner/occupants of a building may require considerable deliberation. The sensitivity of a building's functionality to energy-related variables should dictate the degree of attention allocated in evaluating these factors.

Electrical Energy

Fundamental changes in the purchase of electrical energy are occurring in the United States, affecting access to and regulation of the electric energy industry. Individual electric utility rates and regulations may vary widely during this period of change. Consequently, electrical energy providers and brokers or marketers may need to be contacted to determine the most competitive supplier. Contract conditions need to be reviewed carefully to be sure that the service will suit the purchaser's requirements.

The total cost of electrical energy is usually a combination of several components: energy consumption charges, fuel adjustment charges, special allowances or other adjustments, demand charges, and applicable taxes.

Energy Consumption Charges. Most utility rates have step rate schedules for consumption, and the cost of the last unit of energy consumed may be substantially different from that of the first. The last unit may be cheaper than the first because the fixed costs to the utility may already have been recovered from earlier consumption costs. Alternatively, the last unit of energy may be sold at a higher rate to encourage conservation.

To reflect time-varying operating costs, some utilities charge different rates for consumption according to the time of use and season; typically, costs rise toward the peak period of use. This may justify the cost of shifting the load to off-peak periods.

Fuel Adjustment Charge. Because of substantial variations in fuel prices, electric utilities may apply a fuel adjustment charge to recover costs. This adjustment may not be reflected in the rate schedule. The fuel adjustment is usually a charge per unit of energy and may be positive or negative depending on how much of the actual fuel cost is recovered in the energy consumption rate.

Power plants with multiple generating units that use different fuels typically have the greatest effect on this charge (especially during peak periods, when more expensive units must be brought on-line). Although this fuel adjustment charge can vary monthly, the utility should be able to estimate an average annual or seasonal fuel adjustment for calculations.

Allowances or Adjustments. Special allowances may be available for customers who can receive power at higher voltages or for those who own transformers or similar equipment. Special rates may be available for specific interruptible loads such as domestic water heaters.

Certain facility electrical systems may produce a low power factor, which means that the utility must supply more current on an intermittent basis, thus increasing their costs. These costs may be passed on as an adjustment to the utility bill if the power factor is below a level established by the utility. The power factor is the ratio of real (active) kilowatt power to apparent (reactive) kVA power.

When calculating power bills, utilities should be asked to provide detailed cost estimates for various consumption levels. The final calculation should include any applicable special rates, allowances, taxes, and fuel adjustment charges.

Demand Charges. Electric rates may also have demand charges based on the customer's peak kilowatt demand. Whereas consumption charges typically cover the utility's operating costs, demand charges typically cover the owning costs.

Demand charges may be formulated in a variety of ways:

- *Straight charge*—cost per kilowatt per month, charged for the peak demand of the month.
- *Excess charge*—cost per kilowatt above a base demand (e.g., 50 kW), which may be established each month.
- *Maximum demand (ratchet)*—cost per kilowatt for the maximum annual demand, which may be reset only once a year. This established demand may either benefit or penalize the owner.
- *Combination demand*—cost per hour of operation of the demand. In addition to a basic demand charge, utilities may include further demand charges as demand-related consumption charges.

  The actual demand represents the peak energy use averaged over a specific period, usually 15, 30, or 60 min. Accordingly, high electrical loads of only a few minutes' duration may never be recorded at the full instantaneous value. Alternatively, peak demand is recorded as the average of several consecutive short periods (i.e., 5 min out of each hour).

  The particular method of demand metering and billing is important when load shedding or shifting devices are considered. The portion of the total bill attributed to demand may vary greatly, from 0% to as high as 70%.
- *Real-time* or *time-of-day rates*—An increasing number of utilities are offering rates which reflect the cost of electricity at the time of use. End users who can shift operations or install electric load-shifting equipment, such as thermal storage, can take advantage of such rates. Because these rates usually reflect a utility's overall load profile and possibly the availability of specific generating resources, contact with the supplying utility is essential to determine if these rates are a reasonable option for a specific application.

Natural Gas

Rates. Conventional natural gas rates are usually a combination of two main components: (1) utility rate or base charges for gas consumption and (2) purchased gas adjustment (PGA) charges.

Although gas is usually metered by volume, it is often sold by energy content. The utility rate is the amount the local distribution company charges per unit of energy to deliver the gas to a particular location. This rate may be graduated in steps; the first 10 GJ of gas consumed may not be the same price as the last 10 GJ. The PGA is an adjustment for the cost of the gas per unit of energy to the local utility. It is similar to the electric fuel adjustment charge. The total cost per unit of energy is then the sum of the appropriate utility rate and the PGA, plus taxes and other adjustments.

Interruptible Gas Rates and Contract / Transport Gas. Large industrial plants usually have the ability to burn alternative fuels at the plant and can qualify for special interruptible gas rates. During peak periods of severe cold weather, these customers' supply may be curtailed by the gas utility and they may have to switch to propane, fuel oil, or some other backup fuel. The utility rate and PGA are usually considerably cheaper for these interruptible customers than they are for firm rate (noninterruptible) customers.

Deregulation of the natural gas industry allows end users to negotiate for gas supplies on the open market. The customer actually contracts with a gas producer or broker and pays for the gas at the source. Transport fees must be negotiated with the pipeline companies carrying the gas to the customer's local gas utility. This can be a very complicated administrative process and is usually economically feasible only for large gas users. Some local utilities have special rates for delivering contract gas volumes through their system; others simply charge a standard utility fee (PGA is not applied because the customer has already negotiated with the supplier for the cost of the fuel itself).

When calculating natural gas bills, be sure to determine which utility rate and PGA and/or contract gas price is appropriate for the particular interruptible or firm rate customer. As with electric bills, the final calculation should include any taxes, prompt payment discounts, or other applicable adjustments.

Other Fossil Fuels

Propane, fuel oil, and diesel are examples of other fossil fuels in widespread use. Calculating the cost of these fuels is usually much simpler than calculating typical utility rates. When these fuels are used, other items that can affect owning or operating costs must be considered.

The cost of the fuel itself is usually a simple charge per unit volume or per unit mass. The customer is free to negotiate for the best price. However, trucking or delivery fees must also be included in final calculations. Some customers may have their own transport trucks, but most seek the best delivered price. If storage tanks are not customer-owned, rental fees must be considered. Periodic replacement of diesel-type fuels may be necessary because of storage or shelf-life limitations and must also be considered. The final fuel cost calculation should include any of these costs that are applicable, as well as appropriate taxes.

MAINTENANCE COSTS

The quality of maintenance and maintenance supervision can be a major factor in the energy cost of a building. Chapter 38 covers the maintenance, maintainability, and reliability of systems. Dohrmann and Alereza (1986) obtained maintenance costs and HVAC system information from 342 buildings located in 35 states in the United States. In 1983 U.S. dollars, data collected showed a mean HVAC system maintenance cost of $3.40/m^2$ per year, with a median cost of $2.60/m^2$ per year. The age of the building has a statistically significant but minor effect on HVAC maintenance costs. Analysis also indicated that building size is not statistically significant in explaining cost variation. The type of maintenance program or service agency that building management chooses can also have a significant effect on total HVAC maintenance costs. Although extensive or thorough routine and preventive maintenance programs cost more to administer, they usually produce benefits such as extended equipment life, improved reliability, and less system downtime.

ASHRAE Research Project RP-929 (ASHRAE 1999) was conducted to update and expand the data available on HVAC maintenance costs. The survey included office buildings, medical facilities, retail stores, schools, colleges, and lodging facilities. Statistical analyses were performed on the collected data to determine, which factors significantly affected costs. However, no statistically relevant conclusion could be drawn from the 66 different facility and equipment characteristics that were analyzed.

The data collected measure the total HVAC maintenance costs for a facility (or facilities); they did not measure costs for particular systems or components. The data showed that the mean cost for HVAC maintenance in individual buildings totaled $4.46/m^2$ in 1996 (12 month period immediately preceding survey mailing). The standard deviation of this mean cost was $8.08. The median cost for these same responses was $2.17/m^2$. The huge variance between the mean and median cost was due to very large values (over $50/m^2$) by a few respondents.

The collected data immediately revealed a large difference in maintenance costs for facilities with in-house maintenance personnel and facilities that use outside maintenance firms exclusively. Facilities with in-house maintenance personnel showed a mean annual cost of $4.46/m^2$, a standard deviation of $8.62, and a median cost of $2.70/m^2$. Facilities without in-house maintenance personnel showed a mean cost of $2.13/m^2$, a standard deviation of $3.50, and a median cost of $1.01/m^2$. These values indicate significantly lower costs for facilities that use outside maintenance firms exclusively. However, all of these facilities are conditioned with packaged rooftop units. The facilities with in-house maintenance personnel are conditioned by a wide variety of HVAC system types. Therefore, the type of HVAC equipment may have a large effect on the maintenance costs.

The Building Owners and Managers Association (BOMA) has been collecting HVAC maintenance cost data since the early 1980s. These data are categorized slightly differently than the data collected as part of RP-929, but the two data sets compared favorably for buildings without in-house maintenance personnel, revealing a mean cost for HVAC maintenance in facilities without in-house maintenance personnel of $2.33 m^2. This value is very close to the RP-929 survey mean cost of $2.13/m^2$ for facilities without in-house maintenance personnel. Data for facilities with in-house maintenance personnel could not be compared with the RP-929 results because of significantly different cost accounting. The vast diversity of facility types, sizes, location, operating hours, maintenance procedures, and quality has severely hampered efforts to draw statistically relevant conclusions from survey data.

Considerable service life and maintenance cost data are available, both in the public domain and from proprietary sources used by various commercial service providers. These sources may include manufacturers, ESCOs, insurers, government agencies, and industry-related publications. It is the user's responsibility to obtain these data and to determine the appropriateness and suitability for the application being considered. More traditional, widely used products and components are likely to have statistically reliable records; however, design changes or modifications necessitated by industry changes, such as with refrigerants, may make historical data less reliable.

Newer HVAC products, components, system configurations, control systems and protocols, and upgraded or revived system applications present an additional challenge. Care is required when using data not drawn from broad experience or field reports. In many cases, the information is proprietary or was sponsored by a particular entity or group. Particular care should be taken when using such data. Another important element of estimating owning and operating cost is whether the available industry infrastructure can service and maintain components or system operability. This varies on a national, regional, and local basis and is an important consideration in the selection process; other factors include potential effects from future environmental and energy availability issues.

Estimating Maintenance Costs

Total HVAC maintenance cost for existing buildings with various types of equipment may be estimated using applicable data similar to those shown in Table 4 and the method described below. For equipment types not included in Table 4, or as an alternative estimating method, contact equipment manufacturers or firms that provide maintenance contracts on buildings with similar equipment.

Table 4 Annual HVAC Maintenance Cost Adjustment Factors (in dollars per square metre, 1983 U.S. dollars)

Age Adjustment	+0.019*n*
Heating Equipment (*h*)	
Water tube boiler	+0.083
Cast iron boiler	+0.101
Electric boiler	−0.287
Heat pump	−1.043
Electric resistance	−1.432
Cooling Equipment (*c*)	
Reciprocating chiller	−0.431
Absorption chiller (single stage)*	+2.072
Water-source heat pump	−0.508
Distribution System (*d*)	
Single zone	+0.892
Multizone	−0.502
Dual duct	−0.031
Constant volume	+0.948
Two-pipe fan coil	−0.298
Four-pipe fan coil	+0.624
Induction	+0.734

n = age, years
*These results pertain to buildings with older, single-stage absorption chillers. The data from the survey are not sufficient to draw inferences about the costs of HVAC maintenance in buildings equipped with new absorption chillers.

Several important limitations of the data presented here should be noted:

- Only selected data from Table 12 of the report by Dohrmann and Alereza (1986) are presented here.
- These results should be used for estimating relative costs between central system equipment types as they apply to office buildings only. The data should not be used for estimating maintenance costs for any other systems, equipment, or buildings.
- The data measure total HVAC building maintenance costs, not the costs associated with maintaining particular items or individual pieces of equipment.
- The cost data are not intended for use in selecting new HVAC equipment or systems. This information is for equipment and systems already in place and may not be representative of the maintenance costs expected with newer equipment.
- These results should not be used to predict maintenance costs on a square-metre basis. Actual maintenance costs will vary based on geographic location, type of facility, types, number size and location of equipment to be serviced, equipment application, annual operating hours, local conditions including ambient air quality, and reliability requirements.
- Results were developed from a review of equipment in operation in the early 1980s. The impact of age on equipment repair costs varies significantly by types of HVAC equipment. Significant technology changes in equipment design and application have occurred since the survey was completed. Applying these results to current equipment and systems could result in erroneous conclusions.
- Maintenance of automatic temperature control systems contributes significantly to the maintenance cost for distribution systems. The data presented were developed before the widespread application of electronic and digital control devices in equipment and automatic temperature control systems, which has reduced the amount of maintenance and calibration.

This method assumes that the base HVAC system in the building consists of fire-tube boilers for heating equipment, centrifugal chillers for cooling equipment, and VAV distribution systems. The total annual building HVAC maintenance cost for this system is $3.59/m^2. Adjustment factors from Table 4 are then applied to this base cost to account for building age and variations in type of HVAC equipment as follows:

$$
\begin{aligned}
C &= \text{Total annual building HVAC maintenance cost (\$/m}^2\text{)}\\
&= \text{Base system maintenance costs}\\
&\quad + \text{(Age adjustment factor)} \times \text{(age in years } n\text{)}\\
&\quad + \text{Heating system adjustment factor } h\\
&\quad + \text{Cooling system adjustment factor } c\\
&\quad + \text{Distribution system adjustment factor } d\\
C &= 3.59 + 0.019n + h + c + d
\end{aligned}
$$

Example 1. Estimate the total annual building HVAC maintenance cost per square metre for a building that is 10 years old and has an electric boiler, a reciprocating chiller, and a constant volume distribution system.

$$C = 3.59 + 0.019(10) - 0.287 - 0.431 + 0.948$$

$$C = \$4.01/\text{m}^2 \text{ in 1983 dollars}$$

This estimate can be adjusted to current dollars by multiplying the maintenance cost estimate by the current Consumer Price Index (CPI) divided by the CPI in July 1983. In July 1983, the CPI was 100.1. Monthly CPI statistics are recorded in *Survey of Current Business* (U.S. Department of Commerce). This estimating method is limited to one equipment variable per situation. That is, the method can estimate maintenance costs for a building having either a centrifugal chiller or a reciprocating chiller, but not both. Assessing the effects of combining two or more types of equipment within a single category requires a more complex statistical analysis.

IMPACT OF REFRIGERANT PHASEOUTS

The production phaseout of many commonly used refrigerants has presented building owners with decisions to make regarding the replacement of existing equipment versus retrofit to alternative refrigerant compatibility. Several factors must be considered, including

- **Initial Cost.** New equipment may have a significantly higher installed cost than the retrofit of existing equipment. For example, the retrofit of an existing centrifugal chiller to operate on R-123 may cost 50% of the cost for a new chiller. The cost of rigging a new unit may significantly raise the installed cost, improving the first-cost advantage of conversion.
- **Operating Costs.** The overall efficiency of new equipment is often substantially better than that of existing equipment, depending on age, usage, and level of maintenance performed over the life of the existing unit. In addition, conversion to alternative refrigerants may reduce capacity and/or efficiency.
- **Maintenance Costs.** The maintenance cost for new equipment is generally lower than that for existing equipment. The level of retrofit required to attain compatibility often includes replacement or remanufacture of major unit components, which can bring the maintenance and repair costs in line with those expected of new equipment.
- **Equipment Useful Life.** The impact of a retrofit on equipment useful life is determined by the extent of modification required. The complete remanufacture of a unit should extend the remaining useful life to a level comparable to that of new equipment.

Decisions regarding replacing existing equipment or converting to alternative refrigerants offer opportunities to improve overall system efficiency. Reduced capacity requirements and introduction of new technologies such as variable-speed drives and microprocessor-based controllers can substantially reduce annual operating costs and significantly improve a project's economic benefit.

Information should be gathered to complete Table 1 for each alternative. The techniques described in the section on Economic

Analysis Techniques may then be applied to compare the relative values of each option.

Other Sources

The DOE's Federal Energy Management Program (FEMP) web site (www.eren.doe.gov/femp/procurement) has up-to-date information on energy-efficient federal procurement. Products that qualify for the EPA/DOE Energy Star label are listed on this web site, as are efficiency recommendations, cost effectiveness examples, and purchasing guidance. FEMP also provides web-based cost-calculator tools that simplify the energy cost comparison between products with different efficiencies.

The General Services Administration (GSA) has a basic ordering agreement (BOA) that offers a streamlined procurement method for certain HVAC products based on lowest life-cycle cost. For chillers purchased through commercial sources, the BOA can still be used as a guide in preparing specifications.

OTHER ISSUES

Financing Alternatives

Alternative financing is commonly used in third-party funding of projects, particularly retrofit projects, and is variously called privatization, third-party financing, energy services outsourcing, performance contracting, energy savings performance contracting (ESPC), or innovative financing. In these programs, an outside party performs an energy study to identify or quantify attractive energy-saving retrofit projects and then (to varying degrees) designs, builds, and finances the retrofit program on behalf of the owner or host facility. These contracts range in complexity from simple projects such as lighting upgrades to more detailed projects involving all aspects of energy consumption and facility operation.

Alternative financing can be used to accomplish any or all of the following objectives:

- Upgrade capital equipment
- Provide for maintenance of existing facilities
- Speed project implementation
- Conserve or defer capital outlay
- Save energy
- Save money

The benefits of alternative financing are not free. In general terms, these financing agreements transfer the risk of attaining future savings from the owner to the contractor. The contractor will want to be paid for assuming this risk. In addition, these innovative owning and operating cost reduction approaches have important tax consequences that should be investigated on a case-by-case basis.

There are many variations of the basic arrangements and nearly as many terms to define them. Common nomenclature includes guaranteed savings (performance-based), shared savings, paid from savings, guaranteed savings loans, capital leases, municipal leases, and operating leases. For more information, refer to the U.S. Department of Energy's web site and to the DOE-sponsored document entitled "International Performance Measurement and Verification Protocol." A few examples of alternative financing techniques follow.

Leasing. Among the most common methods of alternative financing is the lease arrangement. In a true lease or lease-purchase arrangement, outside financing provides capital for the construction of a facility. The institution then leases the facility at a fixed monthly charge and assumes responsibility for fuel and personnel costs associated with its operation. Leasing is also commonly available for individual pieces of equipment or retrofit systems and often includes all design and installation costs. Equipment suppliers or independent third parties retain ownership of new equipment and lease it to the user.

Outsourcing. For a cogeneration, steam, or chilled-water plant, either a lease or an energy output contract can be used. An energy output contract enables a private company to provide all the capital and operating costs, such as personnel and fuel, while the host facility purchases energy from the operating company at a variable monthly charge.

Energy Savings. Retrofit projects that lower energy usage create an income stream that can be used to amortize the investment. In **paid-from-savings** programs, utility payments remain constant over a period of years while the contractor is paid out of savings until the project is amortized. In **shared savings** programs, the institution receives a percentage of savings over a longer period of years until the project becomes its property. In a **guaranteed savings** program, the owner retains all the savings and is guaranteed that a certain level of savings will be attained. A portion of the savings is used to amortize the project. In any type of energy savings project, building operation and utilization can have a major impact on the amount of savings actually realized.

Low-Interest Financing. In this arrangement, the supplier offers the equipment with special financing arrangements at below-market interest rates.

Cost Sharing. Several variations of cost-sharing programs exist. In some instances, two or more groups jointly purchase and share new equipment or facilities, thereby increasing use of the equipment and improving the economic benefits for both parties. In other cases, equipment suppliers or independent third parties (such as utilities) who receive an indirect benefit may share part of the equipment or project cost to establish a market foothold for the product.

District Energy Service

District energy service is increasingly available to building owners; district heating and cooling eliminates most on-site heating and cooling equipment. A third party produces treated water or steam and pipes it from a central plant directly to the building. The building owner then pays a metered rate for the energy that is used.

A cost comparison of district energy service versus on-site generation requires careful examination of numerous, often site-specific, factors extending beyond demand and energy charges for fuel. District heating and cooling eliminates or minimizes most costs associated with the installation, maintenance, administration, repair and operation of on-site heating and cooling equipment. Specifically, the costs associated with providing water, water treatment, specialized maintenance services, insurance, staff time, space to house on-site equipment, and structural additions needed to support equipment should be considered. Costs associated with auxiliary equipment, which represent 20 to 30% of the total plant annual operating costs, should also be included.

Any analysis that fails to include all the associated costs does not give a clear picture of the building owner's heating and cooling alternatives. In addition to the tangible costs, there are a number of other factors that should be considered, such as convenience, risk, environmental issues, flexibility, and backup.

On-Site Electrical Power Generation

On-site electrical power generation covers a broad range of applications, from emergency backup to power for a single piece of equipment to an on-site power plant supplying 100% of the facility's electrical power needs. A variety of system types and fuel sources are available, but the economic principles described in this chapter apply equally to all of them. Other chapters (e.g., Chapter 7, Cogeneration Systems and Engine and Turbine Drives, and Chapter 33, Solar Energy Equipment, of the 2000 *ASHRAE Handbook—HVAC Systems and Equipment*) may be helpful in describing system details.

An economic study of on-site electrical power generation should include consideration of all owning, operating, and maintenance costs. Typically, on-site generation is capital intensive (i.e., high first cost) and therefore requires a high use rate to produce savings adequate to support the investment. High use rates mean high run time, which requires planned maintenance and careful operation.

Owning costs include any related systems required to adapt the building to on-site power generation. Additional equipment is required if the building will also use purchased power from a utility. The costs associated with shared equipment should also be considered. For example, if the power source for the generator is a steam turbine, and a hot-water boiler would otherwise be used to meet the HVAC demand, the boiler would need to be a larger, high-pressure steam boiler with a heat exchanger to meet the hot water needs. In addition to higher first cost, operation and maintenance costs for the boiler are increased due to the increased operating hours.

Consideration must also be given to the costs of an initial investment and ongoing inventory of spare parts. Most equipment manufacturers provide a recommended spare parts list as well as recommended maintenance schedules. Typical maintenance schedules consist of daily, weekly, and monthly routine maintenance and periodic major overhauls. Major overhaul frequency depends on equipment utilization and requires taking the equipment off-line. The cost of either lost building use or the provision of electricity from an alternative source during the shutdown should be considered.

ECONOMIC ANALYSIS TECHNIQUES

Analysis of overall owning and operating costs and comparisons of alternatives require an understanding of the cost of lost opportunities, inflation, and the time value of money. This process of economic analysis of alternatives falls into two general categories: simple payback analysis and detailed economic analyses (life-cycle cost analyses).

A simple payback analysis reveals options that have short versus long paybacks. Often, however, alternatives are similar and have similar paybacks. For a more accurate comparison, a more comprehensive economic analysis is warranted. Many times it is appropriate to have both a simple payback analysis and a detailed economic analysis. The simple payback analysis shows which options should not be considered further, and the detailed economic analysis determines which of the viable options are the strongest. The strongest options can be accepted or further analyzed if they include competing alternatives.

Simple Payback

In the simple payback technique, a projection of the revenue stream, cost savings, and other factors is estimated and compared to the initial capital outlay. This simple technique ignores the cost of borrowing money (interest) and lost opportunity costs. It also ignores inflation and the time value of money.

Example 2. Equipment item 1 costs \$10 000 and will save \$2000 per year in operating costs; equipment item 2 costs \$12 000 and saves \$3000 per year. Which item has the best simple payback?

Item 1 \$10 000/(\$2000/yr) = 5 year simple payback

Item 2 \$12 000/(\$3000/yr) = 4 year simple payback

Because the analysis of equipment for the duration of its realistic life can produce a very different result, the simple payback technique should be used with caution.

More Sophisticated Economic Analysis Methods

This section describes a few of the detailed economic techniques available. These techniques are used to examine all costs and incomes to be incurred over the analysis period (1) in terms of their present value (i.e., today's or initial year's value, also called constant value); (2) in terms of equal periodic costs or payments (uniform annualized costs); or (3) in terms of periodic cash flows (e.g., monthly or annual cash flows). Each method provides a slightly different insight. The present value method allows easy comparison of alternatives over the analysis period chosen. The uniform annualized costs method allows comparison of average annual costs of different options. The cash flow method allows comparison of actual cash flows rather than average cash flows; it can identify periods of overall positive and negative cash flow, which is helpful for cash management.

Economic analysis should consider details of both positive and negative costs over the analysis period, such as varying inflation rates, capital and interest costs, salvage costs, replacement costs, interest deductions, depreciation allowances, taxes, tax credits, mortgage payments, and all other costs associated with a particular system. See the section on Symbols for definitions of variables.

Present Value (Present Worth) Analysis. All sophisticated economic analysis methods use the basic principles of present value analysis to account for the time value of money. Therefore, a good understanding of these principles is important.

The total present value (present worth) for any analysis is determined by summing the present worths of all individual items under consideration, both future single payment items and series of equal future payments. The scenario with the highest present value is the preferred alternative.

Single Payment Present Value Analysis. The cost or value of money is a function of the available interest rate and inflation rate. The future value F of a present sum of money P over n periods with compound interest rate i per period is

$$F = P(1+i)^n \tag{1}$$

Conversely, the present value or present worth P of a future sum of money F is given by

$$P = F/(1+i)^n \tag{2}$$

or

$$P = F \times \mathrm{PWF}(i,n)_{sgl} \tag{3}$$

where the single payment present worth factor $\mathrm{PWF}(i,n)_{sgl}$ is defined as

$$\mathrm{PWF}(i,n)_{sgl} = 1/(1+i)^n \tag{4}$$

Example 3. Calculate the value in 10 years at 10% per year interest of a system presently valued at \$10 000.

$$F = P(1+i)^n = \$10\,000(1+0.1)^{10} = \$25\,937.42$$

Example 4. Using the present worth factor for 10% per year interest and an analysis period of 10 years, calculate the present value of a future sum of money valued at \$10 000. (Stated another way, determine what sum of money must be invested today at 10% per year interest to yield \$10 000 10 years from now.)

$$P = F \times \mathrm{PWF}(i,n)_{sgl}$$

$$P = \$10\,000 \times 1/(1+0.1)^{10}$$
$$= \$3855.43$$

Series of Equal Payments. The present worth factor for a series of future equal payments (e.g., operating costs) is given by

$$\mathrm{PWF}(i,n)_{ser} = \frac{(1+i)^n - 1}{i(1+i)^n} \tag{5}$$

Table 5 Annual Capital Recovery Factors

	Rate of Return or Interest Rate, % per Year								
Years	3.5	4.5	6	8	10	12	15	20	25
2	0.526 40	0.534 00	0.545 44	0.560 77	0.576 19	0.591 70	0.615 12	0.654 55	0.694 44
4	0.272 25	0.278 74	0.288 59	0.301 92	0.315 47	0.329 23	0.350 27	0.386 29	0.423 44
6	0.187 67	0.193 88	0.203 36	0.216 32	0.229 61	0.243 23	0.264 24	0.300 71	0.338 82
8	0.145 48	0.151 61	0.161 04	0.174 01	0.187 44	0.201 30	0.222 85	0.260 61	0.300 40
10	0.120 24	0.126 38	0.135 87	0.149 03	0.162 75	0.176 98	0.199 25	0.238 52	0.280 07
12	0.103 48	0.109 67	0.119 28	0.132 70	0.146 76	0.161 44	0.184 48	0.225 26	0.268 45
14	0.091 57	0.097 82	0.107 58	0.121 30	0.135 75	0.150 87	0.174 69	0.216 89	0.261 50
16	0.082 68	0.089 02	0.098 95	0.112 98	0.127 82	0.143 39	0.167 95	0.211 44	0.257 24
18	0.075 82	0.082 24	0.092 36	0.106 70	0.121 93	0.137 94	0.163 19	0.207 81	0.254 59
20	0.070 36	0.076 88	0.087 18	0.101 85	0.117 46	0.133 88	0.159 76	0.205 36	0.252 92
25	0.060 67	0.067 44	0.078 23	0.093 68	0.110 17	0.127 50	0.154 70	0.202 12	0.250 95
30	0.054 37	0.061 39	0.072 65	0.088 83	0.106 08	0.124 14	0.152 30	0.200 85	0.250 31
35	0.050 00	0.057 27	0.068 97	0.085 80	0.103 69	0.122 32	0.151 13	0.200 34	0.250 10
40	0.046 83	0.054 34	0.066 46	0.083 86	0.102 26	0.121 30	0.150 56	0.200 14	0.250 06

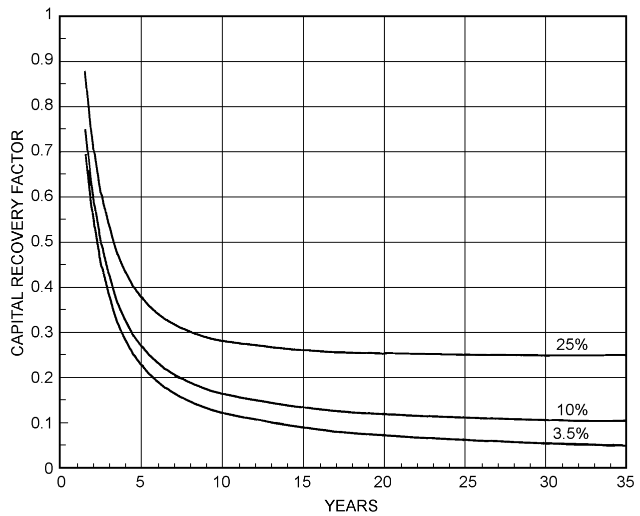

Fig. 1 Capital Recovery Factor Versus Time

The present value P of those future equal payments (PMT) is then the product of the present worth factor and the payment (i.e., $P = \mathrm{PWF}(i,n)_{sgl} \times \mathrm{PMT}$).

The future equal payments to repay a present value of money is determined by the capital recovery factor (CRF), which is the reciprocal of the present worth factor for a series of equal payments:

$$\mathrm{CRF} = \mathrm{PMT}/P \tag{6}$$

$$\mathrm{CRF}(i,n) = \frac{i(1+i)^n}{(1+i)^n - 1} = \frac{i}{1-(1+i)^{-n}} \tag{7}$$

The CRF is often used to describe periodic uniform mortgage or loan payments. Table 5 gives abbreviated annual CRF values for several values of analysis period n and annual interest rate i. Some of the values of Table 5 are plotted versus time in Figure 1.

Note that when payment periods other than annual are to be studied, the interest rate must be expressed per appropriate period. For example, if monthly payments or return on investment are being analyzed, then interest must be expressed per month, not per year, and n must be expressed in months, not years.

Example 5. Determine the present value of an annual operating cost of $1000 per year over 10 years, assuming 10% per year interest rate.

$$\mathrm{PWF}(i,n)_{ser} = [(1+0.1)^{10} - 1]/[0.1(1+0.1)^{10}] = 6.14$$
$$P = \$1000(6.14) = \$6140$$

Example 6. Determine the uniform monthly mortgage payments for a loan of $100 000 to be repaid over 30 years at 10% per year interest. Since we wish monthly payment periods, the payback duration is 30(12) = 360 monthly periods, and the interest rate per period is 0.1/12 = 0.00833 per month.

$$\begin{aligned}\mathrm{CRF}(i,n) &= 0.008\,33(1+0.008\,33)^{360}/[(1+0.008\,33)^{360} - 1] \\ &= 0.008\,773 \\ \mathrm{PMT} &= P(\mathrm{CRF}) \\ &= \$100\,000(0.008\,773) \\ &= \$877.30 \text{ per month}\end{aligned}$$

Improved Payback Analysis. This somewhat more sophisticated payback approach is similar to the simple payback method, except that the cost of money (interest rate, discount rate, etc.) is considered. Solving Equation (7) for n yields the following:

$$n = \frac{\ln[\mathrm{CRF}/(\mathrm{CRF} - i)]}{\ln(1+i)} \tag{8}$$

Given known investment amounts and earnings, CRFs can be calculated for the alternative investments. Subsequently, the number of periods until payback has been achieved can be calculated using Equation (8). Alternatively, a period-by-period (e.g., month-by-month or year-by-year) tabular cash flow analysis may be performed, or the necessary period to yield the calculated CRF may be obtained from a plot of CRFs, such as that shown in Figure 1.

Example 7. Compare the years to payback of the same items described in Example 2 if the value of money is 10% per year.

Item 1

cost = $10 000
savings = $2000/year
CRF = $2000/$10 000 = 0.2
n = ln[0.2/(0.2 – 0.1)]/ln(1 + 0.1) = 7.3 years

Item 2

cost = $12 000
savings = $3000/year
CRF = $3000/$12 000 = 0.25
n = ln[0.25/(0.25 – 0.1)]/ln(1 + 0.1) = 5.4 years

Accounting for Inflation. Different economic goods may inflate at different rates. Inflation reflects the rise in the real cost of a commodity over time and is separate from the time value of money. Inflation must often be accounted for in an economic evaluation. One way to account for inflation is to substitute effective interest rates that account for inflation into the equations given in this chapter.

The effective interest rate i', sometimes called the real rate, accounts for inflation rate j and interest rate i or discount rate i_d; it can be expressed as follows (Kreith and Kreider 1978; Kreider and Kreith 1982):

$$i' = \frac{1+i}{1+j} - 1 = \frac{i-j}{1+j} \tag{9}$$

Different effective interest rates can be applied to individual components of cost. Projections for future fuel and energy prices are available in the *Annual Supplement to NIST Handbook* 135 (Fuller and Boyles 2001; NIST and DOE).

Example 8. Determine the present worth P of an annual operating cost of $1000 over 10 years, given a discount rate of 10% per year and an inflation rate of 5% per year.

$$i' = (0.1 - 0.05)/(1 + 0.05) = 0.0476$$

$$\text{PWF}(i',n)_{ser} = \frac{(1+0.0476)^{10} - 1}{0.0476(1+0.0476)^{10}} = 7.813$$

$$P = \$1000(7.813) = \$7813$$

The following are three commonly used methods of present value analysis that include life-cycle cost factors (life of equipment, analysis period, discount rate, energy escalation rates, maintenance cost, etc., as shown in Table 1). These comparison techniques rely on the same assumptions and economic analysis theories but display the results in different forms. They also use the same definition of each term. All can be displayed as a single calculation or as a cash flow table using a series of calculations for each year of the analysis period.

Savings-to-Investment Ratio. Most large military-sponsored work and many other U.S. government entities require a savings-to-investment-ratio (SIR) method. This method produces a ratio that defines the relative economic strength of each option. The higher the ratio, the better the economic strength. If the ratio is less than 1, the measure does not pay for itself within the analysis period. The escalated savings on an annual and a special (nonannual) basis is calculated and discounted. The costs are shown on an annual and special basis for each year over the life of the system or option. The savings and investments are both discounted separately on an annual basis, and then the discounted total cumulative savings is divided by the discounted total cumulative investments (costs). The analysis period is usually the life of the system or equipment being considered.

Life-Cycle Costs. This method of analysis compares the cumulative total of implementation, operating, and maintenance costs. The total costs are discounted over the life of the system or over the loan repayment period. The costs and investments are both discounted and displayed as a total combined life-cycle cost at the end of the analysis period. The options are compared to determine which has the lowest total cost over the anticipated project life.

Internal Rate of Return. The internal rate of return (IRR) method calculates a return on investment over the defined analysis period. The annual savings and costs are not discounted, and a cash flow is established for each year of the analysis period, to be used with an initial cost (or value of the loan). Annual recurring and special (nonannual) savings and costs can be used. The cash flow is then discounted until a calculated discount rate is found that yields a net present value of zero. This method gives a basic comparison of return on investments. This method assumes savings are reinvested at the same calculated rate of return. Therefore, the calculated rates of return can be overstated compared to the actual rates of return.

Another version of this is the modified or adjusted internal rate of return (MIRR or AIRR). In this version, reinvested savings are assumed to have a given rate of return on investment, and the financed moneys a given interest rate. The cash flow is then discounted until a calculated discount rate is found that yields a net present value of zero. This method gives a more realistic indication of expected return on investment, but the difference between alternatives can be small.

Uniform Annualized Costs Method. It is sometimes useful to project a uniform periodic (e.g., average annual) cost over the analysis period. The basic procedure for determining uniform annualized costs is to first determine the present worth of all costs and then apply the capital recovery factor to determine equal payments over the analysis period.

Uniform annualized mechanical system owning, operating, and maintenance costs can be expressed, for example, as

$$\begin{aligned} C_y = \; & -\text{capital and interest} + \text{salvage value} - \text{replacements} \\ & -\text{disposals} - \text{operating energy} - \text{property tax} \\ & -\text{maintenance} - \text{insurance} \\ & +\text{interest tax deduction} + \text{depreciation} \end{aligned}$$

where

$$\text{capital and interest} = (C_{s,init} - \text{ITC})\text{CRF}(i',n)$$

$$\text{salvage value} = C_{s,salv}\text{PWF}(i',n)\text{CRF}(i',n)(1 - T_{salv})$$

$$\text{replacements or disposals} = \sum_{k=1}^{n} [R_k \text{PWF}(i',k)]\text{CRF}(i',n)(1 - T_{inc})$$

$$\text{operating energy} = C_e[\text{CRF}(i',n)/\text{CRF}(i'',n)](1 - T_{inc})$$

$$\text{property tax} = C_{s,assess}T_{prop}(1 - T_{inc})$$

$$\text{maintenance} = M(1 - T_{inc})$$

$$\text{insurance} = I(1 - T_{inc})$$

$$\text{interest tax deduction} = T_{inc}\sum_{k=1}^{n} [i_m P_{k-1,i}\text{PWF}(i_d,k)]\text{CRF}(i',n)$$

$$\text{depreciation (for commercial systems)} = T_{inc}\sum_{k=1}^{n} [D_k \text{PWF}(i_d,k)]\text{CRF}(i',n)$$

The outstanding principle P_k during year k at market mortgage rate i_m is given by

$$P_k = (C_{s,init} - \text{ITC})\left[(1+i_m)^{k-1} + \frac{(1+i_m)^{k-1} - 1}{(1+i_m)^{-n} - 1}\right] \tag{10}$$

Note: P_k is in current dollars and must, therefore, be discounted by the discount rate i_d, not i'.

Likewise, the summation term for interest deduction can be expressed as

$$\sum_{k=1}^{n} [i_m P_k/(1+i_d)^k] = (C_{s,init} - \text{ITC}) \times$$
$$\left[\frac{\text{CRF}(i_m,n)}{\text{CRF}(i_d,n)} + \frac{1}{(1+i_m)}\frac{i_m - \text{CRF}(i_m,n)}{\text{CRF}[(i_d - i_m)/(1+i_m),n]}\right] \tag{11}$$

If $i_d = i_m$,

$$\sum_{k=1}^{n} [i_m P_k/(1+i_d)^k] = (C_{s,init} - \text{ITC}) \times \left[1 + \frac{n}{1+i_m}[i_m - \text{CRF}(i_m,n)]\right] \tag{12}$$

Depreciation terms commonly used include depreciation calculated by the straight-line depreciation method, which is

$$D_{k,SL} = (C_{s,init} - C_{s,salv})/n \tag{13}$$

and the sum-of-digits depreciation method:

$$D_{k,SD} = (C_{s,init} - C_{s,salv})[2(n-k+1)]/n(n+1) \tag{14}$$

Riggs (1977) and Grant et al. (1982) present further information on advanced depreciation methods. Certified accountants may also be consulted for information regarding accelerated methods allowed for tax purposes. The following example illustrates the use of the uniform annualized cost method. Additional examples are presented by Haberl (1993).

Example 9. Calculate the annualized system cost using constant dollars for a \$10 000 system considering the following factors: a five-year life, a salvage value of \$1000 at the end of the five years, no investment tax credits, a \$500 replacement in year 3, a discount rate i_d of 10%, a general inflation rate j of 5%, a fuel inflation rate j_e of 8%, a market mortgage rate i_m of 10%, an annual operating cost for energy of \$500, a \$100 annual maintenance cost, a \$50 annual insurance cost, straight-line depreciation, an income tax rate of 50%, a property tax rate of 1% of assessed value, an assessed system value equal to 40% of the initial system value, and a salvage tax rate of 50%.

Effective interest rate i' for all but fuel

$$i' = (i_d - j)/(1+j) = (0.10 - 0.05)/(1+0.05) = 0.047\ 619$$

Effective interest rate i'' for fuel

$$i'' = (i_d - j_e)/(1+j_e) = (0.10 - 0.08)/(1+0.08) = 0.018\ 519$$

Capital recovery factor CRF(i', n) for items other than fuel

$$\begin{aligned}\mathrm{CRF}(i',n) &= i'/[1-(1+i')^{-n}] \\ &= 0.047\ 619/[1-(1.047\ 619)^{-5}] = 0.229\ 457\end{aligned}$$

Capital recovery factor CRF(i'',n) for fuel

$$\begin{aligned}\mathrm{CRF}(i'',n) &= i''/[1-(1+i'')^{-n}] \\ &= 0.018\ 519/[1-(1.018\ 519)^{-5}] = 0.211\ 247\end{aligned}$$

Capital recovery factor CRF(i_m, n) for loan or mortgage

$$\begin{aligned}\mathrm{CRF}(i_m,n) &= i_m/[1-(1+i_m)^{-n}] \\ &= 0.10/[1-(1.10)^{-5}] = 0.263\ 797\end{aligned}$$

Loan payment = \$10 000(0.263 797) = \$2637.97

Present worth factor PWF(i_d, years 1 to 5)

$$\mathrm{PWF}(i_d,1) = 1/(1.10)^1 = 0.909\ 091$$

$$\mathrm{PWF}(i_d,2) = 1/(1.10)^2 = 0.826\ 446$$

$$\mathrm{PWF}(i_d,3) = 1/(1.10)^3 = 0.751\ 315$$

$$\mathrm{PWF}(i_d,4) = 1/(1.10)^4 = 0.683\ 013$$

$$\mathrm{PWF}(i_d,5) = 1/(1.10)^5 = 0.620\ 921$$

Present worth factor PWF(i', years 1 to 5)

$$\mathrm{PWF}(i',1) = 1/(1.047619)^1 = 0.954\ 545$$

$$\mathrm{PWF}(i',2) = 1/(1.047619)^2 = 0.911\ 157$$

$$\mathrm{PWF}(i',3) = 1/(1.047619)^3 = 0.869\ 741$$

$$\mathrm{PWF}(i',4) = 1/(1.047619)^4 = 0.830\ 207$$

$$\mathrm{PWF}(i',5) = 1/(1.047619)^5 = 0.792\ 471$$

Capital and interest

$$(C_{s,init} - \mathrm{ITC})\mathrm{CRF}(i',n) = (\$10\ 000 - \$0)0.229\ 457 = \$2294.57$$

Salvage value

$$\begin{aligned}&C_{s,salv}\mathrm{PWF}(i',n)\mathrm{CRF}(i',n)(1-T_{salv}) \\ &= \$1000 \times 0.792\ 471 \times 0.229\ 457 \times 0.5 = \$90.92\end{aligned}$$

Replacements

$$\begin{aligned}&\sum_{k=1}^{n}[R_k \mathrm{PWF}(i',k)]\mathrm{CRF}(i',n)(1-T_{inc}) \\ &= \$500 \times 0.869\ 741 \times 0.229\ 457 \times 0.5 = \$49.89\end{aligned}$$

Operating energy

$$\begin{aligned}&C_e[\mathrm{CRF}(i',n)/\mathrm{CRF}(i'',n)](1-T_{inc}) \\ &= \$500[0.229\ 457/0.211\ 247]0.5 = \$271.55\end{aligned}$$

Property tax

$$C_{s,assess}T_{prop}(1-T_{inc}) = \$10\ 000 \times 0.40 \times 0.01 \times 0.5 = \$20.00$$

Maintenance

$$M(1-T_{inc}) = \$100(1-0.5) = \$50.00$$

Insurance

$$I(1-T_{inc}) = \$50(1-0.5) = \$25.00$$

Interest deduction

$$T_{inc}\sum_{k=1}^{n}[i_m P_{k-1}\mathrm{PWF}(i_d,k)]\mathrm{CRF}(i',n) = \ldots \text{ see Table 6}$$

Table 6 summarizes the interest and principle payments for this example. Annual payments are the product of the initial system cost $C_{s,init}$ and the capital recovery factor CRF(i_m,5). Also, Equation (10) can be used to calculate total discounted interest deduction directly.

Next, apply the capital recovery factor CRF(i',5) and tax rate T_{inc} to the total of the discounted interest sum.

$$\$2554.66\ \mathrm{CRF}(i',5)T_{inc} = \$2554.66 \times 0.229\ 457 \times 0.5 = \$293.09$$

Depreciation

$$T_{inc}\sum_{k=1}^{n}[D_{k,SL}\mathrm{PWF}(i_d,k)]\mathrm{CRF}(i',n)\ldots$$

Use the straight-line depreciation method to calculate depreciation:

$$D_{k,SL} = (C_{s,init} - C_{s,salv})/n = (\$10\ 000 - \$1000)/5 = \$1800.00$$

Next, discount the depreciation.

Year	$D_{k,SL}$	PWF(i_d,k)	Discounted Depreciation
1	\$1800.00	0.909 091	\$1636.36
2	\$1800.00	0.826 446	\$1487.60
3	\$1800.00	0.751 315	\$1352.37
4	\$1800.00	0.683 013	\$1229.42
5	\$1800.00	0.620 921	\$1117.66
		Total	\$6823.41

Finally, the capital recovery factor and tax are applied.

$$\$6823.42\ \mathrm{CRF}(i',n)T_{inc} = \$6823.41 \times 0.229\ 457 \times 0.5 = \$782.84$$

U.S. tax code recommends estimating the salvage value prior to depreciating. Then depreciation is claimed as the difference between the initial and salvage value, which is the way depreciation is treated in this example. A more common practice is to initially claim zero salvage value, and at the end of ownership of the item, treat any salvage value as a capital gain.

Table 6 Interest Deduction Summary (for Example 9)

Year	Payment Amount, Current $	Interest Payment, Current $	Principal Payment, Current $	Outstanding Principal, Current $	PWF(i_d, k)	Discounted Interest, Discounted $	Discounted Payment, Discounted $
0	—	—	—	10 000.00	—	—	—
1	2 637.97	1 000.00	1 637.97	8 362.03	0.909 091	909.09	2 398.17
2	2 637.97	836.20	1 801.77	6 560.26	0.826 446	691.07	2 180.14
3	2 637.97	656.03	1 981.95	4 578.31	0.751 315	492.89	1 981.95
4	2 637.97	457.83	2 180.14	2 398.17	0.683 013	312.70	1 801.77
5	2 637.97	239.82	2 398.17	0	0.620 921	148.91	1 637.97
Total	—	3 189.88	10 000.00	—	—	2 554.66	10 000.00

Table 7 Summary of Cash Flow (for Example 10)

1	2	3	4	5	6	7	8	9	10	11
							Present Worth of Net Cash Flow			
							10% Rate		15% Rate	20% Rate
Year	Cash Outlay, $	Net Income Before Taxes, $	Depreciation, $	Net Taxable Income,[a] $	Income Taxes @50%, $	Net Cash Flow,[b] $	PWF	*P*, $	*P*, $	*P*, $
0	120 000	0	0	0	0	−120 000	1.000	−120 000	−120 000	−120 000
1	0	20 000	15 000	5 000	2500	17 500	0.909	15 900	15 200	14 600
2	0	30 000	15 000	15 000	7500	22 500	0.826	18 600	17 000	15 600
3	0	40 000	15 000	25 000	12 500	27 500	0.751	20 600	18 100	15 900
4	0	50 000	15 000	35 000	17 500	32 500	0.683	22 200	18 600	15 700
5	0	50 000	15 000	35 000	17 500	32 500	0.621	20 200	16 200	13 100
6	0	50 000	15 000	35 000	17 500	32 500	0.564	18 300	14 100	10 900
7	0	50 000	15 000	35 000	17 500	32 500	0.513	16 700	12 200	9 100
8	0	50 000	15 000	35 000	17 500	32 500	0.467	15 200	10 600	7 600
							Total Cash Flow	27 700	2 000	− 17 500
							Investment Value	147 700	122 000	102 500

[a]Net taxable income = net income − depreciation.
[b]Net cash flow = net income − taxes.

Summary of terms

Capital and interest	−$2294.57
Salvage value	+$ 90.92
Replacements	−$ 49.89
Operating costs	−$ 271.55
Property tax	−$ 20.00
Maintenance	−$ 50.00
Insurance	−$ 25.00
Interest deduction	+$ 293.09
Depreciation deduction	+$ 782.84
Total annualized cost	−$1544.16

Cash Flow Analysis Method. The cash flow analysis method accounts for costs and revenues on a period-by-period (e.g., year-by-year) basis, both actual and discounted to present value. This method is especially useful for identifying periods when net cash flow will be negative due to intermittent large expenses.

Example 10. An eight-year study for a $120 000 investment with depreciation spread equally over the assigned period. The benefits or incomes are variable. The marginal tax rate is 50%. The rate of return on the investment is required. Table 7 has columns showing year, cash outlays, income, depreciation, net taxable income, taxes and net cash flow.

Solution: To evaluate the effect of interest and time, the net cash flow must be multiplied by the single payment present worth factor. An arbitrary interest rate of 10% has been selected and PWF_{sgl} is obtained by using Equation (4). Its value is listed in Table 7, column 8. Present worth of the net cash flow is obtained by multiplying columns 7 and 8. Column 9 is then added to obtain the total cash flow. If year 0 is ignored, an investment value is obtained for a 10% required rate of return.

The same procedure is used for 15% interest (column 10, but the PWF is not shown) and for 20% interest (column 11).

Discussion. The interest at which the summation of present worth of net cash flow is zero gives the rate of return. In this example, the investment has a rate of return by interpolation of about 15.4%. If this rate offers an acceptable rate of return to the investor, the proposal should be approved; otherwise, it should be rejected.

Another approach would be to obtain an investment value at a given rate of return. This is accomplished by adding the present worth of the net cash flows, but not including the investment cost. In the example, under the 10% given rate of return, $147 700 is obtained as an investment value. This amount, when using money that costs 10%, would be the acceptable value of the investment.

Computer Analysis

Many computer programs are available that incorporate the economic analysis methods described above. These range from simple macros developed for popular spreadsheet applications to more comprehensive, menu-driven computer programs. Commonly used examples of the latter include Building Life-Cycle Cost (BLCC), Life Cycle Cost in Design (LCCID), and PC-ECONPACK.

BLCC was developed by the National Institute of Standards and Technology (NIST) for the U.S. Department of Energy (DOE). The program follows criteria established by the Federal Energy Management Program (FEMP) and the Office of Management and Budget (OMB). It is intended for the evaluation of energy conservation investments in nonmilitary government buildings; however, it is also appropriate for similar evaluations of commercial facilities.

LCCID is an economic analysis program tailored to the needs of the U.S. Department of Defense (DOD). Developed by the U.S. Army Corps of Engineers and the Construction Engineering Research Laboratory (USA-CERL), LCCID uses economic criteria established by FEMP and OMB.

PC-ECONPACK, developed by the U.S. Army Corps of Engineers for use by the DOD, uses economic criteria established by the OMB. The program performs standardized life-cycle cost calculations such as net present value, equivalent uniform annual cost, SIR, and discounted payback period.

Macros developed for common spreadsheet programs generally contain preprogrammed functions for the various life-cycle cost calculations. Although typically not as sophisticated as the menu-driven programs, the macros are easy to install and easy to learn.

Table 8 Commonly Used Discount Formulas

Name	Algebraic Form[a,b]
Single compound-amount (SCA) equation	$F = P \cdot [(1+d)^n]$
Single present value (SPW) equation	$P = F \cdot \left[\frac{1}{(1+d)^n}\right]$
Uniform sinking-fund (USF) equation	$A = F \cdot \left[\frac{d}{(1+d)^n - 1}\right]$
Uniform capital recovery (UCR) equation	$A = P \cdot \left[\frac{d(1+d)^n}{(1+d)^n - 1}\right]$
Uniform compound account (UCA) equation	$F = A \cdot \left[\frac{(1+d)^n - 1}{d}\right]$
Uniform present value (UPW) equation	$P = A \cdot \left[\frac{(1+d)^n - 1}{d(1+d)^n}\right]$
Modified uniform present value (UPW*) equation	$P = A_0 \cdot \left(\frac{1+e}{d-e}\right) \cdot \left[1 - \left(\frac{1+e}{1+d}\right)^n\right]$

where

A = end-of-period payment (or receipt) in a uniform series of payments (or receipts) over n periods at d interest or discount rate

A_0 = initial value of a periodic payment (receipt) evaluated at the beginning of the study period

$A_t = A_0 \cdot (1+e)^t$, where $t = 1,\ldots, n$

d = interest or discount rate

e = price escalation rate per period

Source: NIST *Handbook* 135 (Ruegg).

[a]Note that the USF, UCR, UCA, and UPW equations yield undefined answers when $d = 0$. The correct algebraic forms for this special case would be as follows: USF formula, $A = F/N$; UCR formula, $A = P/N$; UCA formula, $F = A \cdot n$. The UPW* equation also yields an undefined answer when $e = d$. In this case, $P = A_0 \cdot n$.

[b]The terms by which the known values are multiplied in these equations are the formulas for the factors found in discount factor tables. Using acronyms to represent the factor formulas, the discounting equations can also be written as $F = P \cdot \mathrm{SCA}$, $P = F \cdot \mathrm{SPW}$, $A = F \cdot \mathrm{USF}$, $A = P \cdot \mathrm{UCR}$, $F = \mathrm{UCA}$, $P = A \cdot \mathrm{UPW}$, and $P = A_0 \cdot \mathrm{UPW*}$.

Reference Equations

Table 8 lists commonly used discount formulas as addressed by NIST. Refer to NIST *Handbook* 135 (Ruegg) and Table 2.3 in that handbook for detailed discussions.

SYMBOLS

c = cooling system adjustment factor
C = total annual building HVAC maintenance cost
C_e = annual operating cost for energy
$C_{s,assess}$ = assessed system value
$C_{s,init}$ = initial system cost
$C_{s,salv}$ = system salvage value at end of study period
C_y = uniform annualized mechanical system owning, operating, and maintenance costs
CRF = capital recovery factor
$\mathrm{CRF}(i,n)$ = capital recovery factor for interest rate i and analysis period n
$\mathrm{CRF}(i',n)$ = capital recovery factory for interest rate i' for items other than fuel and analysis period n
$\mathrm{CRF}(i'',n)$ = capital recovery factor for fuel interest rate i'' and analysis period n
$\mathrm{CRF}(i_m,n)$ = capital recovery factor for loan or mortgage rate i_m and analysis period n
d = distribution system adjustment factor
D_k = depreciation during period k
$D_{k,SL}$ = depreciation during period k due to straight-line depreciation method
$D_{k,SD}$ = depreciation during period k due to sum-of-digits depreciation method
F = future value of a sum of money
h = heating system adjustment factor
i = compound interest rate per period
i_d = discount rate per period
i_m = market mortgage rate
i' = effective interest rate for all but fuel
i'' = effective interest rate for fuel
I = insurance cost per period
ITC = investment tax credit
j = inflation rate per period
j_e = fuel inflation rate per period
k = end of period(s) during which replacement(s), repair(s), depreciation, or interest are calculated
M = maintenance cost per period
n = number of periods under analysis
P = present value of a sum of money
P_k = outstanding principle on loan at end of period k
PMT = future equal payments
PWF = present worth factor
$\mathrm{PWF}(i_d,k)$ = present worth factor for discount rate i_d at end of period k
$\mathrm{PWF}(i',k)$ = present worth factor for effective interest rate i' at end of period k
$\mathrm{PWF}(i,n)_{sgl}$ = single payment present worth factor
$\mathrm{PWF}(i,n)_{ser}$ = present worth factor for a series of future equal payments
R_k = net replacement, repair, or disposal costs at end of period k
T_{inc} = net income tax rate
T_{prop} = property tax rate
T_{salv} = tax rate applicable to salvage value of system

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