Related Commercial Resources

CHAPTER 38. OWNING AND OPERATING COSTS

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 effective money management 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 use of either the cheapest or the most expensive system; instead, it demands intelligent analysis of financial objectives and the owner's requirements.

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, intangible items such as aesthetics, acoustics, comfort, safety, security, flexibility, and environmental impact may vary by location and be important to a particular building or facility.

1. 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 completing contract drawings and specifications. To achieve the best performance and economics, alternative methods of solving the engineering problems peculiar to each project should be compared in the early stages of design. Oversimplified estimates can lead to substantial errors in evaluating the system.

The evaluation should lead to a thorough understanding of 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 accuracy in preliminary cost estimates. A reasonable estimate of capital cost of components may be derived from cost records of recent installations of comparable design or from quotations submitted by manufacturers and contractors, or by consulting commercially available cost-estimating guides and software. Table 2 shows a representative checklist for initial 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 (e.g., water treatment)	________		
	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	
	Building Information Model (BIM)
	Computerized Maintenance Management System (CMMS)
	Building Automation and Energy Management System (BAS)
	Terminal or zone controls
	System program control
	Alarms and indicator system
	Automated Fault Detection and Diagnosis (AFDD)
Building Construction and Alteration	
	Mechanical and electrical space
	Chimneys and flues
	Building insulation
	Solar radiation controls
	Acoustical and vibration treatment
	Distribution shafts, machinery foundations, furring

Analysis Period

The time frame over which an economic analysis is performed greatly affects the results. The analysis period is usually determined by specific 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 effect 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

For many years, this chapter included estimates of service lives for various HVAC system components, based on a survey conducted in 1976 under ASHRAE research project RP-186 (Akalin 1978). These estimates have been useful to a generation of practitioners, but changes in technology, materials, manufacturing techniques, and maintenance practices now call into question the continued validity of the original estimates. Consequently, ASHRAE research project TRP-1237 (www.ashrae.org/database) developed an Internet-based data collection tool and database on HVAC equipment service life and maintenance costs, to allow equipment owning and operating cost data to be continually updated and current. The database was seeded with information gathered from a sample of 163 commercial office buildings located in major metropolitan areas across the United States. Abramson et al. (2005) provide details on the distribution of building size, age, and other characteristics. Table 3 presents estimates of median service life for various HVAC components in this sample.

Table 3 Median Service Life

Equipment Type	Median Service Life, Years	Total No. of Units	No. of Units Replaced
DX air distribution equipment	>24	1907	284
Chillers, centrifugal	>25	234	34
Cooling towers, metal	>22	170	24
Boilers, hot-water, steel gas-fired	>22	117	24
Controls, pneumatic	>18	101	25
electronic	>7	68	6
Potable hot-water heaters, electric	>21	304	36

Median service life in Table 3 is based upon analysis of survival curves, which take into account the units still in service and the units replaced at each age (Hiller 2000). Conditional and total survival rates are calculated for each age, and the percent survival over time is plotted. Units still in service are included up to the point where the age is equal to their current age at the time of the study. After that point, these units are censored (removed from the population).

Median service life in this table indicates the highest age at which the survival rate remains at or above 50% for a sample size of 30 or more. There is no hard-and-fast rule about the number of units needed in a sample before it is considered statistically large enough to be representative, but usually the number should be larger than 25 to 30 (Lovvorn and Hiller 2002). This rule of thumb is used because each unit removal represents greater than a 3% change in survival rate as the sample size drops below 30, and that percentage increases rapidly as the sample size gets even smaller.

The database initially developed and seeded under research project TRP-1237 (Abramson et al. 2005) is now available online, providing engineers with equipment service life and annual maintenance costs for a variety of building types and HVAC systems. The database, which includes more than 300 building types and service life data on more than 38 000 pieces of equipment, can be accessed at www.ashrae.org/database.

The database allows users to submit and access up-to-date information to determine a range of statistical values for equipment owning and operating costs. Users are encouraged to contribute their own service life and maintenance cost data, further expanding the utility of this tool. Over time, this input will provide sufficient service life and maintenance cost data to allow comparative analysis of many different HVAC systems types in a broad variety of applications. Data can be entered by logging into the database and registering, which is free. With this, ASHRAE is providing the necessary methods and information to assist in using life-cycle analysis techniques to help select the most appropriate HVAC system for a specific application. This system of collecting data also greatly reduces the time between data collection and when users can access the information.

Figure 1 presents the survival curve for centrifugal chillers, based on data in Abramson et al. (2005). The point at which survival rate drops to 50% based on all data in the survey is 31 years. However, because the sample size drops below the statistically relevant number of 30 units at 25 years, the median service life of centrifugal chillers can only be stated with confidence as >25 years.

Table 4 Comparison of Service Life Estimates

	Median Service Life, Years			Median Service Life, Years			Median Service Life, Years	
Equipment Item	**Abramson et al. (2005)**	**Akalin (1978)**	**Equipment Item**	**Abramson et al. (2005)**	**Akalin (1978)**	**Equipment Item**	**Abramson et al. (2005)**	**Akalin (1978)**
Air Conditioners			**Air Terminals**			**Condensers**		
Window unit	N/A*	10	Diffusers, grilles, and registers	N/A*	27	Air-cooled	N/A	20
Residential single or split package	N/A*	15	Induction and fan-coil units	N/A*	20	Evaporative	N/A*	20
Commercial through-the-wall	N/A*	15	VAV and double-duct boxes	N/A*	20	**Insulation**		
Water-cooled package	>24	15	**Air washers**	N/A*	17	Molded	N/A*	20
Heat pumps			**Ductwork**	N/A*	30	Blanket	N/A*	24
Residential air-to-air	N/A*	15	**Dampers**	N/A*	20	**Pumps**		
Commercial air-to-air	N/A*	15	**Fans**	N/A*		Base-mounted	N/A*	20
Commercial water-to-air	>24	19	Centrifugal	N/A*	25	Pipe-mounted	N/A*	10
Roof-top air conditioners			Axial	N/A*	20	Sump and well	N/A*	10
Single-zone	N/A*	15	Propeller	N/A*	15	Condensate	N/A*	15
Multizone	N/A*	15	Ventilating roof-mounted	N/A*	20	**Reciprocating engines**	N/A*	20
Boilers, Hot-Water (Steam)			**Coils**			**Steam turbines**	N/A*	30
Steel water-tube	>22	24	DX, water, or steam	N/A*	20	**Electric motors**	N/A*	18
Steel fire-tube		25	Electric	N/A*	15	**Motor starters**	N/A*	17
Cast iron	N/A*	35	**Heat Exchangers**			**Electric transformers**	N/A*	30

Electric	N/A*	15	Shell-and-tube	N/A*	24	**Controls**		
Burners	N/A*	21	**Reciprocating compressors**	N/A*	20	Pneumatic	N/A*	20
Furnaces			**Packaged Chillers**			Electric	N/A*	16
Gas- or oil-fired	N/A*	18	Reciprocating	N/A*	20	Electronic	N/A*	15
Unit heaters			Centrifugal	>25	23	**Valve actuators**		
Gas or electric	N/A*	13	Absorption	N/A*	23	Hydraulic	N/A*	15
Hot-water or steam	N/A*	20	**Cooling Towers**			Pneumatic	N/A*	20
Radiant heaters			Galvanized metal	>22	20	Self-contained		10
Electric	N/A*	10	Wood	N/A*	20			
Hot-water or steam	N/A*	25	Ceramic	N/A*	34			

* N/A: Not enough data yet in Abramson et al. (2005). Note that data from Akalin (1978) for these categories may be outdated and not statistically relevant. Use these data with caution until enough updated data are accumulated in Abramson et al.

Table 4 compares the estimates of median service life in Abramson et al. (2005) with those developed with those in Akalin (1978). Most differences are on the order of one to five years.

Estimated service life of new equipment or components of systems not listed in Table 3 or 4 may be obtained from manufacturers, associations, consortia, or governmental agencies. Because of the proprietary nature of information from some of these sources, the variety of criteria used in compiling the data, and the diverse objectives in disseminating them, extreme care is necessary in comparing service life from different sources. Designs, materials, and components of equipment listed in Tables 3 and 4 have changed over time and may have altered the estimated service lives of those equipment categories. Therefore, establishing equivalent comparisons of service life is important.

As noted, service life is a function of the time when equipment is replaced. Replacement may be for any reason, including, but not limited to, failure, general obsolescence, reduced reliability, excessive maintenance cost, and changed system requirements (e.g., building characteristics, energy prices, environmental considerations). Service lives shown in the tables are based on the age of the equipment when it was replaced, regardless of the reason it was replaced.

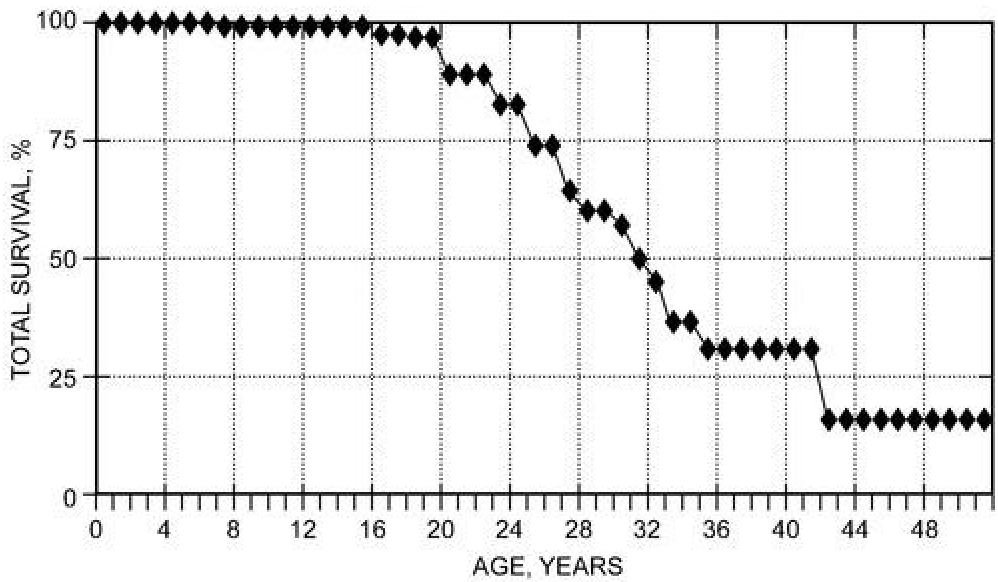

Figure 1. Survival Curve for Centrifugal Chillers [Based on data in Abramson et al. (2005)]

Locations in potentially corrosive environments and unique maintenance variables affect service life. 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 require equipment specifications stating that HVAC equipment located along coastal waters will have corrosion-resistant materials or coatings. 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 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 being designed, but also the adjacent upwind or downwind facilities. HVAC system design for a plant located downwind from a paper mill requires 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 abundant combustion by-products. Both of these contain elevated sulfur oxide and nitrogen oxide concentrations.

- **Maintenance** factors also affect life expectancy. The HVAC designer should temper the service life expectancy of equipment with a **maintenance factor**. To achieve the estimated service life values in Table 3, HVAC equipment must be maintained properly, including good filter-changing practices and good maintenance procedures. For example, chilled-water coils with more than four rows and close fin spacing are virtually impossible to clean even using extraordinary methods; they are often replaced with multiple coils in series, with a maximum of four rows and lighter fin spacing.

Depreciation

Depreciation periods are usually set by federal, state, or local tax laws, which change periodically. Consult applicable tax laws 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 (see Fuller and Petersen [1996] 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 to be used in economic analyses relating to federal expenditures. These discount rates are updated annually (Rushing et al. 2013) 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 because of 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 coverage 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 owning cost. Replacement cost is the cost to remove existing equipment and install new equipment. Salvage value is the value of equipment or its components for recycling or other uses. Equipment's salvage value may be negative when removal, disposal, or decommissioning costs are considered.

2. 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. Energy is a large part of total operating costs. Chapter 19 of the 2021 *ASHRAE Handbook—Fundamentals* outlines how fuel and electrical requirements are estimated. Because most energy management activities are dictated by economics, the facility manager must understand the utility rates that apply to each facility. Electric rates are usually more complex than gas or water rates. In addition to general commercial or institutional electric rates, special rates may exist such as time of day, interruptible service, on-peak/off-peak, summer/winter, and peak demand. Electric rate schedules vary widely in North America. The facility manager should work with local utility companies to identify the most favorable rates and to understand how to qualify for them. The local utility representative can help the facility manager develop the most cost-effective methods of metering and billing. The facility manager must understand the utility rates, including the distinction between marginal and average costs and, in the case of demand-based electric rates, how demand is computed.

Note that, in general, total energy consumption cannot be multiplied by a per-unit energy cost to arrive at a correct annual utility cost, because rate schedules (especially for electricity) often have a sliding scale of prices that vary with consumption, time of day, and other factors.

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 (Rushing et al. 2010). There are no published projection rates for water prices for use 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 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

The total cost of electricity is determined by a rate schedule and is usually a combination of several components: consumption (megajoules), demand (kilowatts) fuel adjustment charges, special allowances or other adjustments, and applicable taxes. Of these, consumption and demand are the major cost components and the ones the owner or facility manager may be able to affect.

Electricity Consumption Charges. Most electric rates have step-rate schedules for consumption, and the cost of the last unit consumed may be substantially different from that of the first. The last unit is usually cheaper than the first because the fixed costs to the utility may already have been recovered from earlier consumption costs. Because of this, the energy analysis cannot use average costs to accurately predict savings from implementation of energy conservation measures. Average costs will overstate the savings possible between alternative equipment or systems; instead, marginal (or incremental) costs must be used.

To reflect time-varying operating costs or to encourage peak shifting, electric utilities may charge different rates for consumption according to the time of use and season, with higher costs occurring during the peak period of use.

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 consumption and may be positive or negative, depending on how much of the actual fuel cost is recovered in the energy consumption rate. The charge may vary monthly or seasonally.

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

Certain facility electrical systems may produce a low power factor (i.e., ratio of real [active] kilowatt power to apparent [reactive] kVA power), 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.

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 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 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*. Cost of electricity at time of use. An increasing number of utilities offer these rates. 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 whether these rates are a reasonable option for a specific application.

Understanding Electric Rates. To illustrate a typical commercial electric rate with a ratchet, electricity consumption and demand data for an example building are presented in Table 5.

The example building in Table 5 is on a ratcheted rate, and bill demand is determined as a percentage of actual demand in the summer. How the ratchet operates is shown in Figure 2.

Table 5 Electricity Data Consumption and Demand for ASHRAE Headquarters, 2003 to 2004

	Billing Days	Consumption, GJ	Actual Demand, kW	Billing Demand, kW	Total Cost, US$
Jan. 2003	29	205.6	178	185	4,118
Feb. 2003	31	222.9	145	185	4,251
Mar. 2003	29	216.2	140	185	4,199
Apr. 2003	29	225.5	154	185	4,271
May. 2003	33	264.4	161	185	4,569
Jun. 2003	26	191.2	171	185	4,007
Jul. 2003	32	242.4	180	185	4,400
Aug. 2003	30	237.6	170	185	4,364
Sep. 2003	32	230.3	149	171	4,127
Oct. 2003	30	198.9	122	171	3,865
Nov. 2003	27	165.7	140	171	3,613
Dec. 2003	34	220.5	141	171	4,028
Total 2003	**362**	**2621.2**			**49,812**
Jan. 2004	31	212.5	145	171	3,967
Feb. 2004	29	195.3	159	171	3,837
Mar. 2004	20	133.5	122	171	2,584

Apr. 2004	12	79.7	133	171	1,547
May. 2004	34	231.3	148	171	4,110
Jun. 2004	29	229.4	148	171	4,321
Jul. 2004	30	248.8	169	169	4,458
Aug. 2004	32	265.7	170	170	4,605
Sep. 2004	29	232.2	166	166	4,281
Oct. 2004	30	216.2	152	161	3,866
Nov. 2004	32	236.7	128	161	4,018
Dec. 2004	31	187.1	132	161	3,646
Total 2004	**339**	**2468.4**			**45,240**

Table 5 shows that the actual demand in the first six months of 2004 had no effect on the billing demand, and therefore no effect on the dollar amount of the bill. The same is true for the last three months of the year. Because of the ratchet, the billing demand in the first half of 2004 was set the previous summer. Likewise, billing demand for the last half of 2004 and first half of 2005 was set by the peak actual demand of 180 kW in July 2003. This tells the facility manager to pay attention to demand in the summer months (June to September) and that demand is not a factor in the winter (October to May) months for this particular rate. (Note that Atlanta's climate is hot and humid; in other climates, winter electric demand is an important determinant of costs.) Consumption must be monitored all year long.

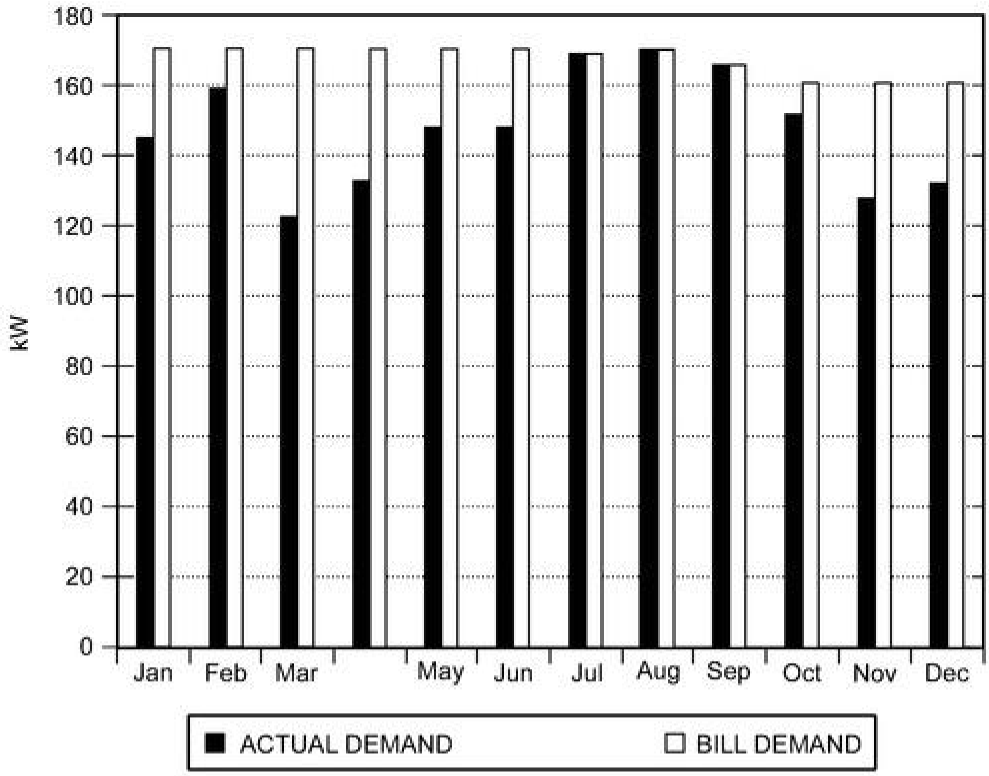

Figure 2. Bill Demand and Actual Demand for Atlanta Example Building, 2004

Understanding the electric rates is key when evaluating the economics of energy conservation projects. Some projects save electrical demand but not consumption; others save mostly consumption but have little effect on demand. Electric rates must be correctly applied for economic analyses to be accurate. Chapter 56 contains a thorough discussion of various electric rates.

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 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 back-up 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.

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.

It is usually difficult, however, to relate usage of stored fossil fuels (e.g., fuel oil) with their operating costs. This is because propane or fuel oil is bought in bulk and stored until needed, and normally not metered or measured as it is consumed, whereas natural gas and power are metered and billed for as they are used.

Energy Source Choices

In planning for a new facility, the designer may undertake **energy master planning**. One component of energy master planning is choice of fuels. Typical necessary decisions include, for example, whether the building should be heated by electricity or natural gas, how service hot water should be produced, whether a hybrid heating plant (i.e., a combination of both electric and gas boilers) should be considered, and whether emergency generators should be fueled by diesel or natural gas.

Decision makers should consider histories or forecasts of price volatility when selecting energy sources. In addition to national trending, local energy price trends from energy suppliers can be informative. These evaluations are particularly important where relative operating costs parity exists between various fuel options, or where selecting more efficient equipment may help mitigate utility price concerns.

Many sources of historic and projected energy costs are available for reference. In addition to federal projections, utility and energy supplier annual reports and accompanying financial data may provide insight into future energy costs. Indicators such as constrained or declining energy supply or production may be key factors in projecting future energy pricing trends. Pricing patterns that suggest unusual levels of energy price volatility should be carefully analyzed and tested at extreme predicted price levels to assess potential effects on system operating costs.

Under conditions of rapidly evolving energy prices or new pricing options, imminent technological improvements, or pending environmental standards and mandates, the adaptability of design options must be carefully evaluated. Where appropriate, contingency planning for accommodating foreseeable alterations to building systems may be prudent. Using diverse energy sources or suppliers in lieu of single sourcing may reduce cost of shifting energy use in the event that single-source pricing becomes volatile, and may even provide negotiating leverage for facility owners.

Water and Sewer Costs

Water and sewer costs have risen in many parts of the country and should not be overlooked in economic analyses. Fortunately, these rates are usually very simple and straightforward: commonly, a charge per m^3 for water and a different charge per m^3 for sewer. Because water consumption is metered and sewage is not, most rates use the water consumption quantity to compute the sewer charge. If an owner uses water that is not returned to sewer, there may be an opportunity to receive a credit or refund. Owners frequently use irrigation meters for watering grounds when the water authority has a special irrigation rate with no sewer charge. Another opportunity that is sometimes overlooked is to separately meter makeup water for cooling towers. This can be done with an irrigation meter if the costs of setting the meter can be justified; alternatively, it may be done by installing an in-line water meter for the cooling tower, in which case the owner reports the usage annually and applies for a credit or refund.

Because of rising costs of water and sewer, water recycling and reclamation is becoming more cost effective. For example, it may now be cost effective in some circumstances to capture cooling coil condensate and pump it to a cooling tower for makeup water.

3. MAINTENANCE COSTS

The quality of maintenance and maintenance supervision can be a major factor in overall life-cycle cost of a mechanical system. The maintenance cost of mechanical systems varies widely depending upon configuration, equipment locations, accessibility, system complexity, service duty, geography, and system reliability requirements. Maintenance costs can be difficult to predict, because each system or facility is unique.

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. Building age 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 extend equipment life; improve reliability; and reduce system downtime, energy costs, and overall life-cycle costs.

Some maintenance cost data are available, both in the public domain and from proprietary sources used by various commercial service providers. These sources may include equipment manufacturers, independent service providers, insurers, government agencies (e.g., the U.S. General Services Administration), and industry-related organizations (e.g., the Building Owners and Managers Association [BOMA]) and service industry publications. 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 alternative refrigerants, may make historical data less relevant.

Newer HVAC products, components, system configurations, control systems and protocols, and upgraded or revised system applications present an additional challenge. Care is required when using data not drawn from broad experience or field reports. In many cases, maintenance information is proprietary or was sponsored by a particular entity or group. Particular care should be taken when using such data. It is the user’s responsibility to obtain these data and to determine their appropriateness and suitability for the application being considered.

Table 6 Comparison of Maintenance Costs Between Studies

	Cost per m^2, as Reported			Cost per m^2, 2004 Dollars	
Survey	**Mean**	**Median**	**Consumer Price Index**	**Mean**	**Median**
Dohrmann and Alereza (1983)	$3.44	$2.58	99.6	$6.57	$4.95
Abramson et al. (2005)	$5.06	$4.74	188.9	$5.06	$4.74

ASHRAE research project TRP-1237 (Abramson et al. 2005) developed a standardized Internet-based data collection tool and database on HVAC equipment service life and maintenance costs. The database was seeded with data on 163 buildings from around the country. Maintenance cost data were gathered for total HVAC system maintenance costs from 100 facilities. In 2004 dollars, the mean HVAC maintenance cost from these data was $5.06/m^2, and the median cost was $4.74/m^2. Table 6 compares these figures with estimates reported by Dohrmann and Alereza (1983), both in terms of contemporary dollars, and in 2004 dollars, and shows that the cost per square metre varies widely between studies.

Estimating Maintenance Costs

Total HVAC maintenance cost for new and existing buildings with various types of equipment may be estimated several ways, using several resources. Equipment maintenance requirements can be obtained from the equipment manufacturers for large or custom pieces of equipment. Estimating in-house labor requirements can be difficult; BOMA (2003) provides guidance on this topic. Many independent mechanical service companies provide preventative maintenance contracts. These firms typically have proprietary estimating programs developed through their experience, and often provide generalized maintenance costs to engineers and owners upon request, without obligation.

When evaluating various HVAC systems during design or retrofit, the absolute magnitude of maintenance costs may not be as important as the relative costs. Whichever estimating method or resource is selected, it should be used consistently throughout any evaluation. Mixing information from different resources in an evaluation may provide erroneous results.

Applying simple costs per unit of building floor area for maintenance is highly discouraged. Maintenance costs can be generalized by system types. When projecting maintenance costs for different HVAC systems, the major system components need to be identified with a required level of maintenance. The potential long-term costs of environmental issues on maintenance costs should also be considered.

Factors Affecting Maintenance Costs

Maintenance costs are primarily a measure of labor activity. System design, layout, and configuration can significantly affect the amount of time and effort required for maintenance and, therefore, the maintenance cost. Factors to consider when evaluating maintenance costs include the following:

- **Quantity and type of equipment.** Each piece of equipment requires a core amount of maintenance and time, regardless of its size or capacity. A greater number of similar pieces of equipment are generally more expensive to maintain than larger but fewer units. For example, one manufacturer suggests the annual maintenance for centrifugal chillers is 24 h for a nominal 3500 kW chiller and 16 h for a nominal 1800 kW chiller. Therefore, the total maintenance labor for a 3500 kW chiller plant with two 1800 kW chillers would be 32 h, or 1/3 more than a single 3500 kW chiller.
- **Equipment location and access.** The ability to maintain equipment in a repeatable and cost-effective manner is significantly affected by the equipment's location and accessibility. Equipment that is difficult to access increases the amount of time required to maintain it, and therefore increases maintenance cost. Equipment maintenance requiring erection of ladders and scaffolding or hydraulic lifts increases maintenance costs while likely reducing the quantity and quality of maintenance performed. Equipment location may also dictate an unusual working condition that could require more service personnel than normal. For example, maintenance performed in a confined space (per OSHA [Annual] definitions) requires an additional person to be present, for safety reasons.
- **System run time.** The number of hours of operation for an HVAC system affects maintenance costs. Many maintenance tasks are dictated by equipment run time. The greater the run time, the more often these tasks need to be performed.
- **Critical systems.** High-reliability systems require more maintenance to ensure uninterrupted system operation. Critical system maintenance is also usually performed with stringent shutdown and failsafe procedures that tend to increase the amount of time required to service equipment. An office building system can be turned off for a short time with little effect on occupants, allowing maintenance almost any time. Shutdown of a hospital operating room or pharmaceutical manufacturing HVAC system, on the other hand, must be coordinated closely with the operation of the facility to eliminate risk to patients or product. Maintenance on critical systems may sometimes incur labor premiums because of unusual shutdown requirements.
- **System complexity.** More complex systems tend to involve more equipment and sophisticated controls. Highly sophisticated systems may require highly skilled service personnel, who tend to be more costly.
- **Service environment.** HVAC systems subjected to harsh operating conditions (e.g., coastal and marine environments) or environments like industrial operations may require more frequent and/or additional maintenance.
- **Local conditions.** The physical location of the facility may require additional maintenance. Equipment in dusty or dirty areas or exposed to seasonal conditions (e.g., high pollen, leaves) may require more frequent or more difficult cleaning of equipment and filters. Additional maintenance tasks may be needed.
- **Geographical location.** Maintenance costs for remote locations must consider the cost of getting to and from the locations. Labor costs for the number of anticipated trips and their duration for either in-house or outsourced service personnel to travel to and from the site must be added to the maintenance cost to properly estimate the total maintenance cost.
- **Equipment age.** The effect of age on equipment repair costs varies significantly by type of HVAC equipment. Technologies in equipment design and application have changed significantly, affecting maintenance costs.
- **Available infrastructure.** Maintenance costs are affected by the availability of an infrastructure that can maintain equipment, components, and systems. Available infrastructure varies on a national, regional, and local basis and is an important consideration in the HVAC system selection process.

4. REFRIGERANT PHASEOUTS

Production phaseout of many commonly used refrigerants has required building owners to decide between replacing existing equipment or retrofitting for alternative refrigerants. Several factors must be considered, including

- **Initial Cost.** New equipment may have a significantly higher installed cost than retrofitting existing equipment. For example, retrofitting an existing centrifugal chiller to operate on R-123 may cost 50% of the cost for a new chiller, making the installation cost of a new chiller seem a prudent alternative. Conversely, the cost of rigging a new unit may significantly raise the installed cost, improving the first-cost advantage of refrigerant 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 of the existing equipment.
- **Maintenance Costs.** The maintenance cost for new equipment is generally lower than that for existing equipment. However, the level of retrofit required to attain compatibility between existing equipment and new refrigerant 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 effect of a retrofit on equipment useful life is determined by the extent of modification required. Complete remanufacture of a unit should extend the remaining useful life to a level comparable to that of new equipment.

Replacing existing equipment or converting to alternative refrigerants can 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) (energy.gov/eere/femp/find-product-categories-covered-efficiency-programs) has up-to-date information on energy-efficient federal procurement. Products that qualify for the EPA/DOE ENERGY STAR label are listed, 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 some 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.

5. FINANCING ALTERNATIVES

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, for which the contractor is paid. 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, see the U.S. Department of Energy's website and DOE (2007). 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 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 use can strongly affect the amount of savings actually realized.

Low-Interest Financing. In this arrangement, the supplier offers 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.

Alternative Property-Based Financing for Building and Energy-Related Upgrades. One common challenge for implementing energy-efficient upgrades (even with excellent internal rate of return or savings-to-investment parameters) is simply getting someone to commit the financing or credit line to fund the project. This is especially problematic in a building where tenant occupancy is high. Although the overall energy savings gained by the project might yield a great payback, the challenge stems from uncertainty as to how tenants will benefit and building owner concerns over not having a method for recouping the investment.

Property assessment for clean energy (PACE) is a method for providing financing that is based on increasing the municipal tax base for funding energy reduction methods (ERMs). This approach can yield energy savings for the building and does not affect the building or property owner's credit rating or their ability to borrow. The goal is to offset the added tax costs with the energy savings of the ERMs. Life-cycle costs over the life of the funding must be carefully considered and maintained to accepted ASHRAE standards.

PACE relies on being recognized, accepted, and adopted into local tax laws. Over half the U.S. states have accepted PACE, but it is not currently well developed or even accepted in all locations. The structure and interest rate of PACE is a function of firms providing the PACE process and the actual funding.

Currently, 16 states have approved this type of municipal tax-based funding for specifically energy-efficient upgrades in buildings. The exact mechanics for the program vary by location and by state), but typically involve an investment-grade building energy audit to ASHRAE standards. This provides a reasonably reliable method with which to pick the internal rate of return (see the section on Internal Rate of Return, under Economic Analysis Techniques) of different ERMs.

Once the different ERMs are evaluated, the life-cycle cost analysis can be completed (see the section on Life-Cycle Costs, under Economic Analysis Techniques). The goal is for the ERMs to save more energy than the increase to the municipal tax base, so that the overall ownership or life-cycle costs are decreased. To pass on energy savings to a building's tenants, condo owners, and other occupants without putting a financial burden on the building owner(s), the following must be achieved:

- A skillfully executed, investment-grade energy audit executed to ASHRAE standards
- Selection of effective ERMs
- Proper life-cycle operation
- Proper maintenance of the ERMs

The U.S. Department of Energy (DOE) and other material in the Bibliography are good sources for more in-depth information. Note that the way PACE is administered by local municipalities changes according to location.

Property owners who choose to participate in a PACE program repay their ERMs over a set period (typically 5 to 30 years) through property assessments. Such assessments are secured by the property itself and become an added payment on the owner's property tax bills or are ultimately paid for by the tenants or businesses through common-area maintenance fees or operational costs. When PACE projects are properly structured and maintained, the energy savings achieved can be greater than the costs of owning and operating the building and provide a realized monthly savings from the first year through the life of the improvement. PACE projects present a solution for owners and tenants who do not want to commit credit resources to provide needed ERMs and building improvements. If the building is sold, the assessment or financing stays with the property in the form of a tax assessment.

Table 7 Key Pros and Cons of PACE

Pros	Cons
Allows for secure financing of comprehensive projects over terms up to 30 years	Available only to property owners; renters cannot access programs directly
Repayment obligation passes with ownership, overcoming hesitancy to invest in longer payback measures	Cannot finance portable items
Senior lien municipal financing may lead to low interest rates	Requires dedicated staff time
Interest portion of assessment repayments are tax deductible	High legal and administrative expenses to set up
Lower transaction costs compared to private loans	Not appropriate for investments below $50 000
Allows municipalities to encourage energy efficiency and renewable energy without putting their general funds at risk	Some resistance by lenders whose priority in default may be reduced

Source: DOE (2013).

A general sequence of PACE process is shown in Figure 3.

Because the PACE assessment is a debt that is tied to the property and not the property owners, depending on state laws, the assessment can transfer with the building and the repayment obligation does not affect building owners. This lack of obligation for the property owner eliminates a key opposition to investing in ERMs, because many property owners may not own the building long enough to enjoy the savings as opposed to the initial cost. Other owners simply will be hesitant to use scarce financial resources when they might not benefit directly from lower utility bills.

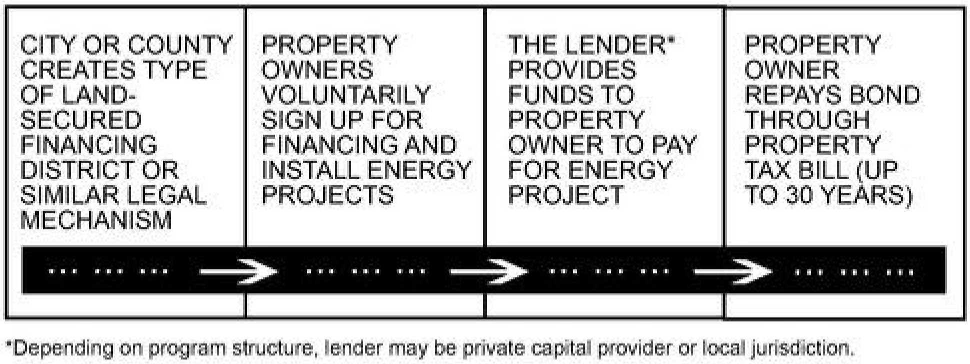

Figure 3. PACE Process (based on DOE 2013)

Table 7 summarizes the key advantages and disadvantages of PACE for property owners.

Key steps local governments may follow to implement a commercial PACE program include the following:

1. **Review and address issues:** Become familiar with issues related to PACE and factor their consequences into program design and implementation.
2. **Establish supporting framework:** Lay a solid foundation for the program in the areas of team composition, goals, legislation, and assessment district formation.
3. **Choose capital sourcing approach(es):** Choose whether the projects will be funded using private capital, and if so, whether the program will use an open- or closed-market approach.
4. **Determine whether and how to deploy credit enhancement:** Decide how to achieve the best interest rates for the program and how best to apply and leverage any available funds to fit the program's design.
5. **Choose eligible property types:** Select the commercial property types eligible for the program.
6. **Assemble eligible project measures:** Determine what types of improvements can be financed based on enabling legislation and program goals.
7. **Choose energy audit requirements:** Decide the types of energy audits applicants will be required to undergo to assess expected project energy/cost savings.
8. **Choose program eligibility criteria:** Determine the program underwriting/eligibility criteria that applicants and their properties must meet. See DOE (2013) for guidance.
9. **Leverage existing utility rebate/incentive programs:** Investigate local utility rebate/incentive programs and how best to leverage them.
10. **Plan quality assurance/quality control:** Decide how the program will ensure that project work meets program quality standards and how to guard against fraud.

11. **Design application processing procedures:** Design the process for reviewing applications and either approving or rejecting them.
12. **Specify contractor requirements:** Specify the requirements for energy auditors and contractors to participate in the program.
13. **Market and launch program:** Decide what kind of outreach will be made to property owners and contractors, and launch the program.

Note that many steps are carried out concurrently and not necessarily in this exact order. Often, an additional step for procurement is appropriate to choose capital and/or administration entities.

Note that although PACE is an alternative to traditional financing, as with all energy saving or performance-based methods, the actual performance data, parameters, and assumptions of energy modeling and analysis of projected costs, along with real-world operating conditions and operators' varying skill levels, lead to changing energy and life-cycle costs.

6. DISTRICT ENERGY VS ON-SITE GENERATION

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 installation, maintenance, administration, repair, and operation of on-site heating and cooling equipment. Specifically, 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 back-up.

On-Site Electrical Power Generation

On-site electrical power generation covers a broad range of applications, from emergency back-up to power for a single piece of equipment to an on-site power plant supplying 100% of the facility's electrical power needs. Various 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., Chapters 7 and 37 of the 2020 *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. 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. Operation and maintenance costs for the boiler also are increased because of the increased operating hours.

Costs of an initial investment and ongoing inventory of spare parts must also be considered. Most equipment manufacturers provide a recommended spare parts list as well as recommended maintenance schedules, typically daily, weekly, and monthly routine maintenance and periodic major overhauls. Major overhaul frequency depends on equipment use 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.

7. 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 1. 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 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

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

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

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

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

Example 2. 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 3. 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.)

$$P = F \times \text{PWF}(i,n)_{sgl}$$
$$P = \$10\,000 \times 1/(1 + 0.1)^{10}$$
$$= \$3855.43$$

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

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

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

The number of 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:

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

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

The CRF is often used to describe periodic uniform mortgage or loan payments.

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.

Example 4. 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 5. Determine the uniform monthly mortgage payments for a loan of $100 000 to be repaid over 30 years at 10% per year interest. Because the payment period is monthly, 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).

Example 6. 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

If years to payback is the sole criteria for comparison, Item 2 is preferable because the investment is repaid in a shorter period of time.

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 (Kreider and Kreith 1982):

$$i' = \frac{1+i}{1+j} - 1 = \frac{i-j}{1+j} \quad \textbf{(9)}$$

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 (Rushing et al. 2010).

Example 7. 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 common 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. Simply put, SIR is the ratio of an option's savings to its costs. This ratio 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. Costs are shown on an annual and special basis for each year over the life of the system or option. 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.

The SIR is the sum of a series of operation-related savings from a project alternative divided by the sum of its additional investment-related costs. Typically, this is over a period of years (5, 10, or 20 years, or the typical expected life span).

The general equation for the SIR simply rearranges these two terms as a ratio:

$$\text{SIR}_{\text{A:BC}} = \frac{\sum_{t=0}^{N} S_t/(1+d)^t}{\sum_{t=0}^{N} I_t/(1+d)^t} \quad \textbf{(10)}$$

where

$\text{SIR}_{\text{A:BC}}$	=	ratio of PV savings to additional PV investment costs of (mutually exclusive) alternative A to base case BC
S_t	=	savings in year t in operational costs attributable to alternative
I_t	=	investment-related costs in year t attributable to alternative
t	=	year of occurrence (where 0 is base date)
d	=	discount rate
N	=	length of study

A more practical SIR base-case equation for buildings is as follows:

(11)

$$SIR_{A:BC} = \frac{E + W + OM\&R}{I_o + Repl - Res}$$

where

$SIR_{A:BC}$	=	ratio of operational savings to investment-related additional costs computed for alternative A to base case BC
E	=	$(E_{BC} - E_A)$, savings in energy costs attributable to alternative relative to base case
W	=	$(W_{BC} - W_A)$, savings in water costs attributable to alternative
OM&R	=	difference in OM&R costs; $OM\&R_{BC} - OM\&R_A$
I_o	=	additional initial investment cost required for alternative relative to base case; $(I_A - I_{BC})$
Repl	=	difference in capital replacement costs; $(Repl_A - Repl_{BC})$
Res	=	difference in residual value; $(Res_A - Res_{BC})$

where all amounts are in present values.

Example 8: SIR Computation. For this example, the numerator and denominator are defined as follows:

Numerator: PV of operational savings attributable to the alternative = \$91 030

Denominator: PV of additional investment costs required for the alternative = \$7239

Thus,

$$SIR_{A:BC} = \frac{\$91\ 030}{\$7239} = 12.6$$

A ratio of 12.6 means that the energy-conserving design generates an average return of \$12.6 for every \$1 invested, over and above the minimum required rate of return imposed by the discount rate. The project alternative in this example is clearly cost effective. A ratio of 1.0 indicates that the cost of the investment equals its savings; a ratio of less than 1.0 indicates an uneconomic alternative that would cost more than it would save.

Summary of SIR Method

- An investment is cost effective if its SIR is greater than 1.0; this is equivalent to having net savings greater than zero.
- The SIR is a relative measure; it must be calculated with respect to a designated base case.
- When computing the SIR of an alternative relative to its base case, the same study period and the same discount rate must be used.
- The SIR is useful for evaluating a single project alternative against a base case or for ranking independent project alternatives; it is not useful for evaluating multiple mutually exclusive alternatives.

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 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.

The most straightforward method of calculating the AIRR requires that the SIR for a project (relative to its base case) be calculated first. Then the AIRR can be computed easily using the following equation:

$$AIRR = (1 + r)(SIR)^{1/N} - 1 \quad \textbf{(12)}$$

where r is the reinvestment rate and N is the number of years in the study period. Using the SIR of 12.6 from Equation (10) and a reinvestment rate of 3% (the minimum acceptable rate of return [MARR]), the AIRR is found as follows:

$$AIRR_{A:BC} = (1 + 0.03)(12.6)^{1/20} - 1 = 0.1691$$

Because an AIRR of 16.9% for the alternative is greater than the MARR, which in this example is the FEMP discount rate of 3%, the project alternative is considered to be cost effective in this application.

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.

Table 8 Two Alternative LCC Examples

Alternative 1: Purchase Chilled Water from Utility

	Year										
	0	1	2	3	4	5	6	7	8	9	10
First costs		—	—	—	—	—	—	—	—	—	—
Chilled-water costs		$65 250	$66 881	$68 553	$70 267	$72 024	$73 824	$75 670	$77 562	$79 501	$81 488
Replacement costs		—	—	—	—	—	—	—	—	—	—
Maintenance costs		—	—	—	—	—	—	—	—	—	—
Net annual cash flow		65 250	66 881	68 553	70 267	72 024	73 824	75 670	77 501	79 501	81 488
Present value of cash flow		60 417	57 340	54 420	51 648	49 018	46 522	44 153	41 904	39 770	37 745
		Year									
		11	12	13	14	15	16	17	18	19	20
Financing annual payments		—	—	—	—	—	—	—	—	—	—
Chilled-water costs		$83 526	$85 614	$87 754	$89 948	$92 197	$94 501	$96 864	$99 286	$101 768	$104 312
Replacement costs		—	—	—	—	—	—	—	—	—	—
Maintenance costs		—	—	—	—	—	—	—	—	—	—
Net annual cash flow		83 526	85 614	87 754	89 948	92 197	94 501	96 864	99 286	101 768	104 312
Present value of cash flow		35 823	33 998	32 267	30 624	29 064	27 584	26 179	24 846	23 581	22 380
20-year life-cycle cost	$769 823										

Alternative 2: Install Chiller and Tower

	Year										
	0	1	2	3	4	5	6	7	8	9	10
First costs	$220 000	—	—	—	—	—	—	—	—	—	—
Energy costs		$18 750	$19 688	$20 672	$21 705	$22 791	$23 930	$25 127	$26 383	$27 702	$29 087
Replacement costs		—	—	—	—	—	—	—	—	—	90 000
Maintenance costs		15 200	15 656	16 126	16 609	17 108	17 621	18 150	18 694	19 255	19 833
Net annual cash flow	220 000	33 950	35 344	36 798	38 315	39 898	41 551	43 276	45 077	46 957	138 920
Present value of cash flow	220 000	31 435	30 301	29 211	28 163	27 154	26 184	25 251	24 354	23 490	64 347
		Year									
		11	12	13	14	15	16	17	18	19	20
Financing annual payments		—	—	—	—	—	—	—	—	—	—
Energy costs		$30 542	$32 069	$33 672	$35 356	$37 124	$38 980	$40 929	$42 975	$45 124	$47 380
Replacement costs		—	—	—	—	—	—	—	—	—	—
Maintenance costs		20 428	21 040	21 672	22 322	22 991	23 681	24 392	25 123	25 877	26 653
Net annual cash flow		50 969	53 109	55 344	57 678	60 115	62 661	65 320	68 099	71 001	74 034

Present value of cash flow		21 860	21 090	20 350	19 637	18 951	18 290	17 654	17 042	16 452	15 884
20-year life-cycle cost	$717 100										

Example 9. A municipality is evaluating two different methods of providing chilled water for cooling a government office building: purchasing chilled water from a central chilled-water utility service in the area, or installing a conventional chiller plant. Because the municipality is not a tax-paying entity, the evaluation does not need to consider taxes, allowing for either a current or constant dollar analysis.

The first-year price of the chilled-water utility service contract is $65 250 per year and is expected to increase at a rate of 2.5% per year.

The chiller and cooling tower would cost $220 000, with an expected life of 20 years. A major overhaul ($90 000) of the chiller is expected to occur in year ten. Annual costs for preventative maintenance ($1400), labor ($10 000), water ($2000) and chemical treatments ($1800) are all expected to keep pace with inflation, which is estimated to average 3% annually over the study period. The annual electric cost ($18 750) is expected to increase at a rate of 5% per year. The municipality uses a discount rate of 8% to evaluate financial decisions.

Which option has the lowest life-cycle cost?

Solution. Table 8 compares the two alternatives. For the values provided, alternative 1 has a 20-year life-cycle cost (LCC) of $769 283 and alternative 2 has a 20-year life-cycle cost of $717 100. If LCC is the only basis for the decision, alternative 2 is preferable because it has the lower life-cycle cost.

Computer Analysis

Many computer programs are available that incorporate economic analysis methods. 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) 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 evaluation of energy conservation investments in nonmilitary government buildings; however, it is also appropriate for similar evaluations of commercial facilities.

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 various life-cycle cost calculations. Although typically not as sophisticated as the menu-driven programs, the macros are easy to install and learn.

Reference Equations

Table 9 lists commonly used discount formulas as addressed by NIST. Refer to NIST *Handbook* 135 (Fuller and Petersen 1996) for detailed discussions.

8. SYMBOLS

AIRR = modified or adjusted internal rate of return (MIRR or AIRR)

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
CRF(i,n)	=	capital recovery factor for interest rate i and analysis period n

CRF(i',n)	=	capital recovery factory for interest rate i' for items other than fuel and analysis period n
CRF(i'',n)	=	capital recovery factor for fuel interest rate i'' and analysis period n
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 from straight-line depreciation method
$D_{k,SD}$	=	depreciation during period k from sum-of-digits depreciation method
F	=	future value of 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
PWF(i_d,k)	=	present worth factor for discount rate i_d at end of period k
PWF(i',k)	=	present worth factor for effective interest rate i' at end of period k
PWF$(i,n)_{sgl}$	=	single payment present worth factor
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
SIR	=	savings-to-investment ratio
T_{inc}	=	net income tax rate
T_{prop}	=	property tax rate
T_{salv}	=	tax rate applicable to salvage value of system

Table 9 Commonly Used Discount Formulas

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

Uniform capital recovery (UCR) equation	$$A = P\left[\frac{d(1+d)^n}{(1+d)^n - 1}\right]$$

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_t	=	$A_0(1 + e)^t$, where $t = 1, \ldots, n$
			d	=	interest or discount rate
A_0	=	initial value of a periodic payment (receipt) evaluated at beginning of study period	e	=	price escalation rate per period

Source: NIST *Handbook* 135 (Fuller and Petersen 1996).

[a] Note that the USF, UCR, UCA, and UPV 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, $F = An$. The UPV* equation also yields an undefined answer when $e = d$. In this case, $P = A_0 n$.

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

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