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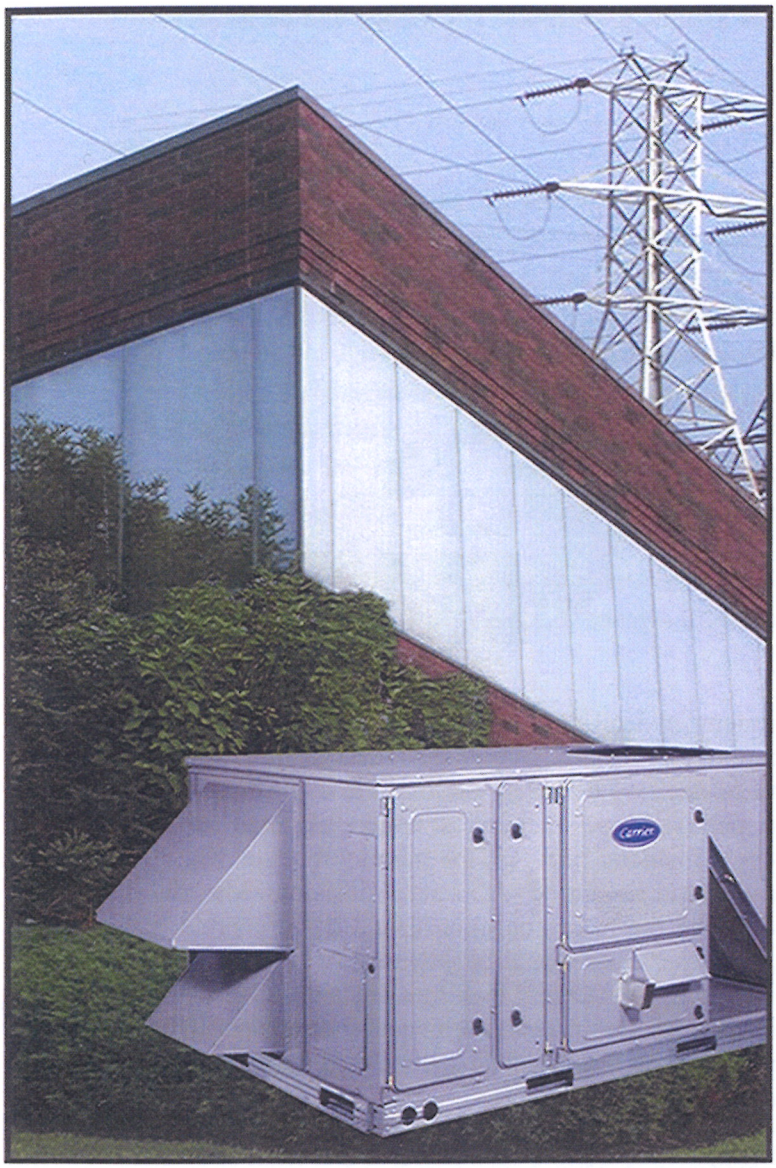


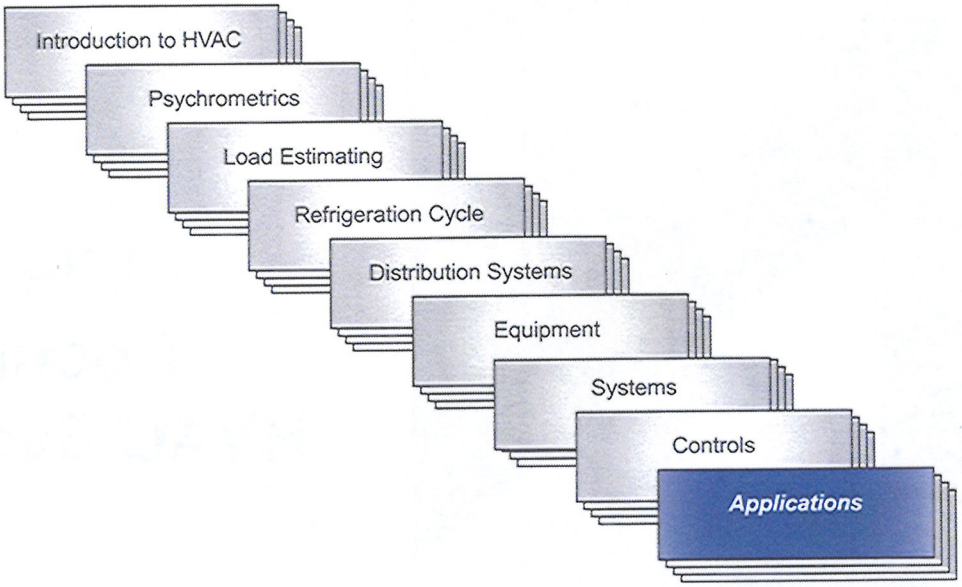
APPLICATIONS

Life Cycle Costing for HVAC Systems

Technical Development Program

Technical Development Programs (TDP) are modules of technical training on HVAC theory, system design, equipment selection and application topics. They are targeted at engineers and designers who wish to develop their knowledge in this field to effectively design, specify, sell or apply HVAC equipment in commercial applications.

Although TDP topics have been developed as stand-alone modules, there are logical groupings of topics. The modules within each group begin at an introductory level and progress to advanced levels. The breadth of this offering allows for customization into a complete HVAC curriculum Ödfrom a complete HVAC design course at an introductory-level or to an advanced-level design course. Advanced-level modules assume prerequisite knowledge and do not review basic concepts.



Decisions about the type of HVAC system or decisions related to making HVAC system modifications are based of financial justification. The federal government, sustainable design projects and many other entities require that these decision be based the total life cycle costs rather that first cost alone. The life cycle costing method is one of the most commonly used decision making methods of determining total life cycle financial impact. This training module discusses the life cycle costing method and how it should be applied to HVAC related decisions. Material is divided into six sections. These sections describe the basic concepts behind the life cycle cost method, a recommended procedure to follow, what data should be included, where to find the data and several techniques to be used in evaluating the data and making a decision. Also covered are payback and several other decision-making tools. This material can equally be applied to public or privately funded projects with certain guidelines. This module will explain these guidelines and demonstrate a life cycle costing software program.

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Printed in Syracuse, NY

CARRIER CORPORATION
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Table of Contents

Introduction 1
Using the Life Cycle Cost Method 2
Time Value of Money 3
Comparative Economic Measures 3
Reasons to use Life Cycle Costing 3
Life Cycle Costing Procedure 5
Life Cycle Costing Method Defined 5
Steps in the Life Cycle Costing Procedure 6
Getting Started 7
Timing of the Study 7
Level of Effort 7
Level of Documentation 8
Types of Decisions for Project Alternatives 8
Mutually Exclusive Alternatives 8
Independent Alternatives 8
Interdependent Alternatives 9
Types of Decisions 10
Defining the Project and Selecting Alternatives 10
Choosing the Study Period 11
Types of Cost 12
Income versus Cost-Based Analyses 12
Public Sector versus Private Sector Analyses 13
Analysis Techniques 14
Discount Rate 14
Future Value (Compounding) 15
Present Value (Discounting) 15
Inflation 17
Cost Escalation, *e* 17
Cash Flow 18
Economic Factor Tables 19
Collecting Data 19
Cost Estimating 19
Investment Costs 19
First Cost 20
Capital Replacement Costs 20
Residual Value 20
Utility Rebates and Incentives 21
Taxes 21
Insurance 23
Finance Costs 23
Revenues 27
Non-Economic Benefit 27
Operating and Maintenance Costs 27
Electric Energy Costs 28
Natural Gas Costs 34
Other Utility Costs 34
Water Costs 35
Operating and Maintenance Costs 35
Economic Evaluations 35
Simple Payback (SPB) 36
Return on Investment (ROI) 36

Discounted Payback 37
Annual Cost (AC) Method 38
Life Cycle Cost (LCC) Method or Present Value Analysis 39
Internal Rate of Return Method 40
Net Savings (NS) Method 42
Savings-to-Investment Ratio (SIR) Method 43
Economic Evaluation Criteria 49
Prioritize Independent Competing Projects with or without Funding Constraints 52
Special Topics 54
Value Engineering 54
Uncertainty and Sensitivity Analysis 55
Breakeven Analysis 56
Depreciation 57
Straight-Line Method 57
Sum-of-Years-Digits Method 58
Double-Declining Balance Method 59
Modified Accelerated Cost Recovery System (MACRS) Method 60
Non-Economic Evaluation 60
Analysis Tools 61
Spreadsheet Methods 61
Economic Analysis Software 62
Example Life Cycle Cost Analysis 62
Summary 68
Work Session 1 69
Work Session 2 72
Work Session 1 Answers 78
Work Session 2 Answers 80
Appendix A – Economic Formula 85
Future Value (Compounding) 85
Present Value (Discounting) 86
Uniform Series Investments 87
Uniform Capital Recovery (UCR) 89
Inflation 91
Escalation 91
Appendix B – Additional Resources 93
References 94
Glossary 95

Introduction

The need to reduce HVAC energy usage has become an industry trend due to increased energy prices and owners desiring to reduce operating costs. At the same time, there is an equally powerful force, primarily owner-driven, to minimize the installed costs of new and replacement HVAC systems. There is a delicate balance between these two influences. Reductions in energy consumption are often achieved by installing higher-efficiency systems with increased initial cost. The owner or owner's agent must carefully analyze various systems and scenarios to determine the most economical life cycle cost. This generally involves simultaneously analyzing future operating and maintenance costs against the initial installed cost of the system.

An emerging trend in the building industry is sustainable design. This holistic design approach analyzes the entire building from site selection and design to demolition for its impacts on use of material and energy resources, the comfort and productivity of the occupants, and the financial benefits of ownership. To fairly evaluate the tradeoffs involved in these decisions the financial impacts over the building's entire life cycle need to be evaluated. Life cycle costing methods are the tools used to evaluate these decisions.

Today's building owners have varying goals and objectives. However, most desire to simultaneously reduce operating and maintenance expenses while retaining tenants and increasing profitability. To achieve these objectives most owners utilize economic analysis techniques to improve their decision-making during the planning, design, and construction phases of a building. Additionally, federal, state, and municipal entities have enacted code-legislated energy mandates (such as ASHRAE Standard 90.1), which set minimum energy-efficiency requirements for commercial buildings. Economic impact is an integral consideration as stated in Standard 90.1, "all sections of the new standard should apply the economic approach as consistently as possible to ensure that the standard was balanced among the respective sections (e.g., envelope, lighting, mechanical)." The standards authors recognized the importance of considering both the economics and energy usage when performing a building analysis.

Determining energy usage is a major step in calculating the life cycle operating cost. Computer software programs are available to simplify computing annual energy consumption of various system designs and upgrade alternatives. The determination of annual energy costs is not discussed within this text; it is assumed that those costs have already been calculated. You should refer to related publications for information on methods for calculating annual energy costs.

This Technical Development Program (TDP) covers how the principles of life cycle costing are applied to common HVAC decisions. The text describes a recommended procedure to use in determining and calculating life cycle costs and explains common methods to compare alternatives for decision-making. In addition, tips are provided on where to find required data and how to handle special economic conditions related to the building construction industry. A section of the text demonstrates how software analysis tools are used for life cycle cost calculations. Finally, a glossary of related terms and a section explaining basic economic calculation formula is provided at the end of the text, if you are not familiar with these terms or calculations. Example problems are used throughout to illustrate and reinforce understanding of these concepts. Two work sessions are also included to assist you in evaluating your understanding of these concepts.

Using the Life Cycle Cost Method

Our first step is to understand what life cycle costing is. The life cycle costing method is an economic decision making tool used to evaluate alternatives based on all relevant costs related to owning, operating, maintaining, and disposing of the project. Life cycle costing is appropriate for decisions related to buildings and particularly HVAC systems because of the impact the first cost decision will have long-term annual costs. HVAC decisions often involve more than a simple tradeoff of long term energy costs compared to increased first cost but may involve issue such as occupant comfort, system reliability, maintenance considerations, and even environmental impacts. Life cycle costing translates all these costs into monetary terms. The basic premise of life cycle costing is that savings resulting from future operating and maintenance expense will justify additional owning expense, normally the result of higher first cost. Figure 1 shows how four alternatives compare when all the costs are compared; the savings in energy and maintenance expense help justify the increased system first cost. In life cycle costing, the alternative with the lowest life cycle cost is considered the best alternative. In some cases, however, a high cost alternative may be used because it provides better non-economic value, such as greater comfort control or aesthetics.

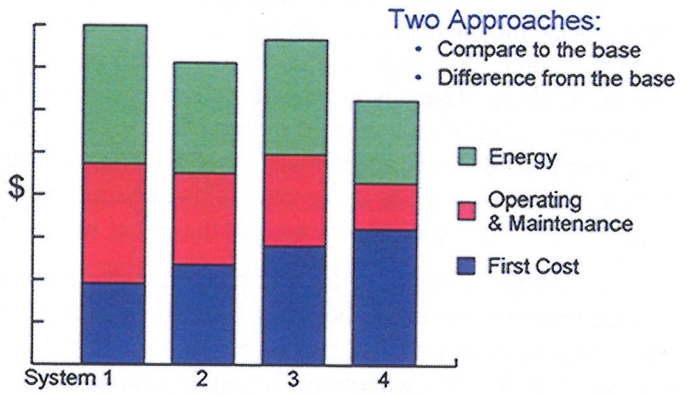


Figure 1

Comparison of Project Alternatives Using Life Cycle Costs

Before proceeding with how to calculate life cycle costs, it is important to understand some key issues related to its use. Life cycle costing methods do not determine the absolute value of future costs or savings. Life cycle costing methods are a decision making tool. Savings resulting from future costs are based on numerous projections of energy usage, costs increases, repair requirements, and useful life. Unanticipated changes in these can significantly change the resulting savings. However, as long as all the alternatives are evaluated based on the same assumptions the resulting decision between alternatives is still valid.

The second issue is that alternatives need to be compared at a common point in time. The time when costs and savings occur varies with each project alternative. This timing is important because of changes in the value of money and the owners acceptable time period of the study. A fair comparison of alternatives can only be achieved if the timing of all the costs is brought to a common point in time. The life cycle costing method uses the timing convention of bringing all costs that occur within the study period to their equivalent present dollar value. Residual value of the alternatives after the study period should also be accounted for to reach a fair decision. Issues of escalating costs, inflation, and deprecation affect the present value of alternatives and need to be addressed in life cycle costing decisions.

Finally, not all project costs need to be included. Because the goal of performing an analysis is to make a decision between alternatives, it is only necessary to consider the costs that vary between alternatives. For example in comparing two chillers, if the cost of the starter is the same, it need not be considered.

Time Value of Money

The concept of money having a value over time is fundamental to understanding or performing any economic or financial analysis. Money has a time value because it can be invested at some interest rate and increases in value over time. Conversely, if the money is not invested or spent, there is a lost opportunity to invest the money resulting in a decrease in value. At the same time, inflation is eroding the value of money and decreasing its purchasing power. Therefore, an accurate economic analysis technique always accounts for the time value of money.

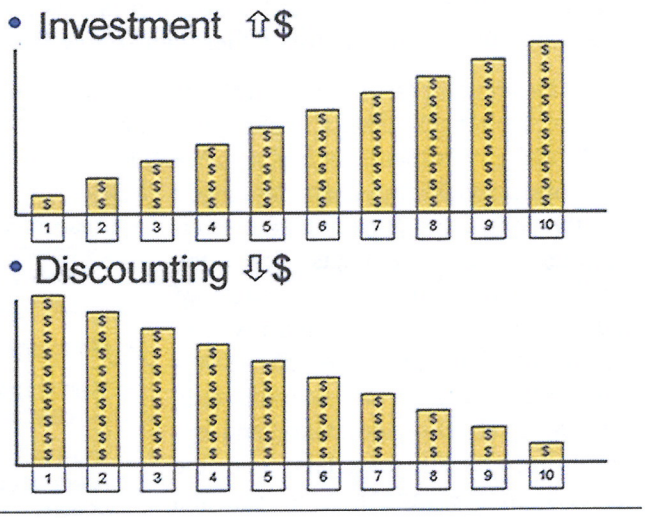


Figure 2

The Time Value of Money – Compounding or Discounting

Life cycle costing methods discount all future costs to determine their present worth value. The use of discounting takes the perspective that the current investment in the project results in lost opportunity to invest somewhere else.

Comparative Economic Measures

In life cycle costing, determining the present worth value is just the first step in comparing alternatives. There are several types of decisions in selecting alternatives. For example, one decision may involve the choice of doing a project or making a repair to the existing systems, while another may involve determining the most cost effective alternative between several efficiency levels, and a third may involve deciding which of many profitable projects should be funded with limited funds. A second part of the life cycle costing procedure is using evaluation techniques that help make these decisions. The most common are Payback (PB), Internal Rate of Return (IRR), Net Savings (NS), Saving to Investment Ratio (SIR), and Annual Cost (AC). These methods will be explained later in this text as well as discussing when it is appropriate to apply each method.

Reasons to use Life Cycle Costing

Life cycle costing techniques are not new, and some building owners have evaluated life cycle HVAC system costs for years. However, interest in using long-term financial evaluation methods of HVAC projects has dramatically increased in the last few years. This is due to four key driving issues.

First, government entities have enacted legislation requiring publicly funded projects evaluate the life cycle cost impact of project alternatives. On the federal level, a program known as the "Greening of Government" called for major energy reductions and reducing the associated cost to government. As a part of this effort President Clinton issued Executive Order 13123, which required that by 2004 all federally funded projects would use life cycle costing as the basis for selecting project alternatives. This impacted construction decisions for every branch of the

military, every courthouse, post office, and every other type of government building. A number of states have issued similar orders for projects funded by the state such as California, New York, Pennsylvania, and Maryland. Local governments have done the same requiring that decisions be based on the long-range costs rather than simple first cost savings.

The second reason the importance life cycle costing has increased is a trend in green buildings or sustainable design, which are a form of life cycle evaluation. In addition to federal, state, and local governments, public organizations, and private businesses are embracing this new trend to evaluate building decisions based on the long-term impact to the environment. The impacts on the environment include: the impacts of the building on the community and site where it is located; its use of water and energy; the manufacture, disposal, recycling potential, and energy impacts of materials; and the affects on the indoor environmental quality as it influences the health and productivity of occupants. These are a diverse group of requirements with different evaluation criteria. Because most building decisions involve trade-offs between some of these requirements, the only fair way to evaluate trade-offs is by relating the impacts using monetary measures. The goal of sustainability is to minimize the building's impacts. Therefore, comparing these trade-off decisions using life cycle costing methods is a natural application of the methodology.



Figure 3

Reasons for Doing a Life Cycle Cost Analysis

Rising concerns over energy usage and availability are also causing building owners to make the long term cost of energy a part of their HVAC system decision making process. It is important for building owners responsible for utility bills to use life cycle costing in their decision process. Even when owners pass the costs of utilities on to tenants, the tenants are beginning to factor their decision on where to lease based in part on energy costs. As pointed out before, more energy efficient systems normally have a greater initial cost. Building owners and developers can make the best financial decisions when first cost decisions are balanced with lifetime impacts of operating costs and rents. Once again, life cycle costing methods provide the best evaluation tool.

Life Cycle Costing Method:

- ***Is a decision making tool between project alternatives***
- ***Considers all the relevant costs between options***
- ***Brings all costs to a common point in time***
- ***Use decision-making criteria to select between alternatives***

Finally, business owners are tending to view buildings from a different perspective. Every building is seen as an investment and cost. The trend was once that business large and small owned their buildings; this view is changing. Now firms specialize in owning and sometimes operating buildings. If a firm operating a building reduces energy and operating costs, they will increase their profitability. Today, groups invest in buildings the same way groups have invested in stocks; these are REITS (real estate investment trusts). To REITS, a building is an investment like a common stock. Even when owners are not paying utilities, buildings that are more efficient can better attract and retain tenants, sometimes at higher rents. These factors make building ownership more profitable. Even a trend in the building appraisal industry, which uses the net operating income to determine the building's value, is causing owners to be more conscious of long-term costs.

Life Cycle Costing Procedure

Life Cycle Costing Method Defined

Let's start by expanding on the definition of life cycle costing presented in the last section.

The life cycle costing method is an economic decision-making tool used to evaluate alternatives based on all relevant costs related to owning, operating, maintaining, and disposing of the project alternatives. The process selects one alternative as the base, normally the one with lowest first cost, and compares other alternatives to this base.

The LCC Method is a comprehensive method that accounts for all costs differences incurred and benefits received. This is the most useful and most widely applicable economic analysis method. It can be used for all types of analysis decisions except for rank ordering or prioritizing independent projects. The SIR or IRR methods are required for those types of projects, which are covered in later sections.

The LCC includes the costs to acquire, design, construct, operate, maintain, and subsequently dispose of the facility or system. The generalized life cycle cost (LCC) equation is written as follows:

Equation 1

$$LCC = I + R + E + W + OM\&R - RV$$

Where:

I	=	capital investment costs
R	=	capital replacement costs
E	=	energy costs
W	=	water costs
OM&R	=	operating, maintenance & repair costs
RV	=	residual value (salvage less disposal costs)

All costs are translated into present value (PV) terms. Capital investment costs are assumed to occur at the beginning of the study period and are therefore already in PV terms. Other costs may occur at different times over the economic life and are all discounted to their respective PV using appropriate discount and cost escalation factors. Finally, the PV of each component cost is summed to arrive at the total (LCC). The alternative with the lowest LCC is the most favorable alternative.

The first thing that needs to be done for a life cycle cost analysis is to determine the initial cost of each alternative and determine the residual value at the end of the life cycle. We will discuss this in more detail in the next section of this text.

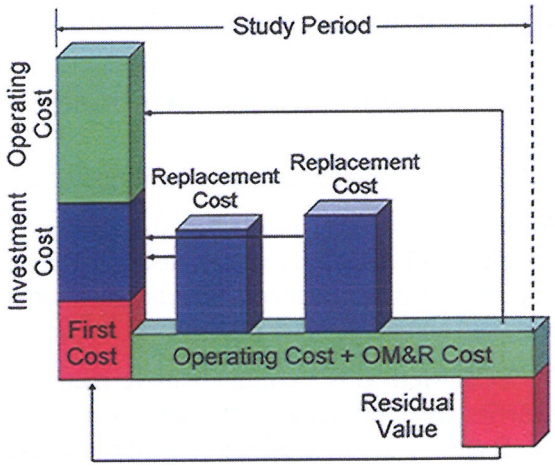


Figure 4

Life Cycle Cost Analysis – Moving All Costs to Present Value

To perform a life cycle cost analysis, the annual operating cost for utilities needs to be determined. This is done by conducting an energy analysis for one year and then projecting costs for the life cycle. Once the annual operating costs have been determined, the next step is to obtain installation and maintenance costs for the proposed equipment or systems. Many sources exist for installation and maintenance costs. References are included in the Appendix. Whenever possible, it is recommended that you obtain these costs locally from contractors and equipment suppliers since local cost data is generally much more accurate and useful than national averages.

After installation and maintenance costs have been determined, the present value of each alternative is calculated using the formula, a spreadsheet or other software program and a Life Cycle Cost (LCC) Analysis is performed to determine the life cycle cost of each alternative. One of several methods of economic decision-making is then used to determine the best economic alternative.

Steps in the Life Cycle Costing Procedure

Prior to undertaking any economic cost analysis, the desired results and consequences of all decisions made should be clearly defined. This includes collecting and assembling all pertinent cost related data. A recommended procedure follows:

1. Clearly define the problem and the desired objective.
2. Determine whether an economic analysis is even necessary. If so, decide the level of sophistication and complexity required to satisfy the desired objective.
3. Identify and list all potential alternatives for accomplishing the desired objective, considering all possible constraints.
4. Establish the common economic elements. Set the life cycle period considering useful lives of building or system component under analysis. Determine the appropriate discount rate based on the owners financial objectives.
5. Select a suitable economic analysis method(s).
6. Compile all pertinent cost data and list assumptions required by the particular economic analysis method(s) selected.
7. Calculate each alternatives LCC present worth.
8. Perform economic analysis calculations.
9. Evaluate non-economic criteria and determine costs and benefits
10. Document the results.

Compare and contrast the results. Be sure to take into account all non-quantifiable (qualitative) parameters. For instance, if a new HVAC system is installed in a particular building that makes the tenants more comfortable, perhaps they will not move-out and relocate to a new facility. Be sure to consider the need for a sensitivity analysis. Remember that the results are based on future projections. For example, the results of the study may change significantly if electricity costs increase at a higher rate than in the projections.

Getting Started

Before we begin to accumulate the data and crunch the numbers, a few decisions need to be made about the study. Life cycle costing studies can be extremely complicated involving numerous costs and detailed financial calculations. We should first determine how detailed a calculation is required and what level of documentation is required. We must also determine when the project start and when the benefits will actually begin. These decisions and more can dramatically impact an analysis. We need to understand these issues before we begin calculating.

Timing of the Study

At what point in the design process does it make sense to calculate the life cycle costs? It is most practical to perform studies at a number of points in the design process. This is particularly true if the project is a sustainable design project where one of the goals is to assess the life cycle impact of each alternative decision. LCC analyses make good sense early in the design process since at this point the effort to make changes can result in the largest rewards. For example, in the schematic design when system selection is taking place, LCC can be used to determine the best system alternative. However, LCC analysis is as appropriate latter in the process for example when the best efficiency unit needs to be selected. LCC can even be valuable when the job has been bid and savings need to be found to proceed, an LCC analysis can help make the best value engineering decisions. Design decisions have the greatest impact on life cycle project costs and these occur early in the process as indicated in Figure 5.

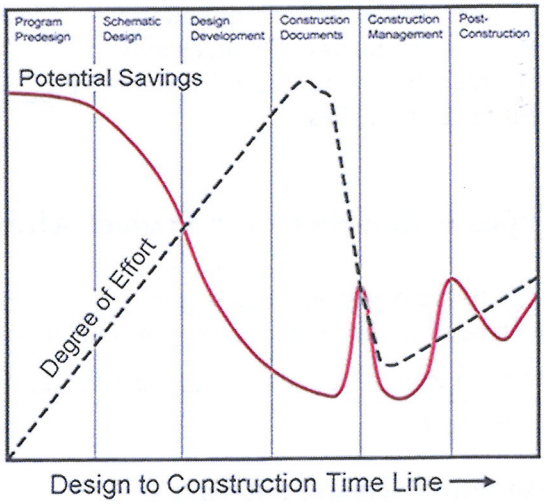


Figure 5

Perform LCC Analysis Early in the Design for Greatest Impact

Level of Effort

As with any job, it is important to select the right tool for LCC analyses. Effort in time and resources are required to perform an analysis, the level of effort should reflect the needs of a study. For example, if the goal of an analysis is to determine if an air handler should have high or standard efficiency motors, does not require an analysis that calculates the full air handler cost including installation. In this case, a full energy analysis is probably not even required. Since

most of the costs are the same, a simple payback based on the savings using the total number of annual operating hours will give us the results we need. While this case may be extreme, the example is appropriate. Look at the results that you hope to obtain from a study and then determine what level of detail will adequately reflect this goal. In some cases, you may determine no analysis is even required as the result is intuitive.

Level of Documentation

Documentation can be very important in doing a life cycle cost analysis. Assumptions are often made when analyzing the financials in life cycle cost studies. Often, if a hole is found in one part of the analysis, the results of the entire study are in question. To avoid questioning of the results, provide adequate documentation that supports the assumptions made. However, as mentioned above, adjust the documentation to meet the effort and depth of the analysis. Doing so will minimize time spent preparing the documentation and prevent unnecessary assumptions or depth of analysis that will potentially present opportunity for results to be questioned. Figure 6 is the items of documentation recommended by the federal government for LCC studies.

- Project Description
  - General description
  - Type of decision
  - Constraints
- Alternatives
  - Description
  - Rationale for selection
  - Non-economic considerations
- Common Parameters
  - Study Period
  - Base Date
  - Service Date
  - Discount Rate
  - Inflation
  - Operational Assumptions
  - Energy / Water Price Schedules
- Cost Data
  - Investment related costs
  - Operating related costs
  - Energy usage types / Amounts
  - Water usage and disposal
  - Timing of costs
  - Cost data sources
  - Uncertainty assessment
- Computations
  - Discounting
  - Life Cycle Costs
  - Supplementary
- Interpretation
  - Results / Sensitivity
- Non Monetary Cost / Benefit
- Other Considerations
- Recommendations

Figure 6

Documentation for Life Cycle Cost Studies

Types of Decisions for Project Alternatives

Life cycle costing studies deal with a wide variety of alternative types and decision situations. The type of decision required depends on the alternatives and the desired outcome.

Most economic decisions encountered in the HVAC business involve one of three alternative types:

Mutually Exclusive Alternatives

With this type of analysis, only one alternative may be selected from among those available. In other words, selecting one alternative eliminates all other alternatives from consideration. An example of mutual exclusivity is selecting the optimum type of windows for a building. There are many levels of thermal efficiency and performance available, yet we can only select one type of window, excluding all others from consideration.

Independent Alternatives

This type of project consists of multiple alternatives that can each be implemented simultaneously, each without affecting the cost effectiveness of the other. The important thing to understand here is that each project alternative being considered must have already been

identified as being cost effective. It is assumed that each alternative has already been evaluated relative to the other mutually exclusive alternatives available. Therefore, an analysis of mutually exclusive alternatives should be performed prior to analyzing independent alternatives.

This type of analysis is typically required when funding is limited to implement the most cost effective projects. For instance, suppose the owner of an older building is considering remodeling and the scope includes resurfacing the parking lot, landscaping, new carpet and wallpaper, and a new HVAC system. Depending on budget constraints, one or more of these projects could be implemented. While the HVAC system can be evaluated quantitatively, the aesthetic improvements are more difficult to quantify. Perhaps they will help attract or retain new tenants, increasing the owner's bottom line. Of course, the rate of return will depend on prevailing real estate markets, vacancy rates and the general economic performance.

With this type of analysis, project alternatives are prioritized and funded until the budget is depleted. The trick is finding the optimum combination of alternatives that together yields the lowest overall life cycle cost (LCC) for the project, while using the largest amount of the available budget. Depending on the available budget, it may be prudent to selecting a higher first-cost option with a lower rate of return rather than a low first-cost option even though it has a higher rate of return. If the budget is unlimited, project alternatives are prioritized (rank-ordered) and funded in descending order of highest rate of return to lowest.

Interdependent Alternatives

This is the most complex type of analysis and is usually conducted for new buildings only. An analysis involving interdependent alternatives requires the simultaneous evaluation of multiple building systems or components with the goal of optimizing the efficiency and minimizing the LCC of the entire building. This interaction between individual building systems means that changes in one system may affect the performance of another. For example, the thermal efficiency of the building envelope directly affects the HVAC system. As the envelope becomes tighter, the energy savings diminishes due to improved HVAC system efficiency. Likewise, as the HVAC system efficiency increases, the economic benefit of an improved building envelope diminishes.

Determining the optimal combination of building systems that minimize the total building energy consumption requires that a simultaneous energy analysis be performed. This is sometimes referred to as a whole-building analysis. Various software programs exist to perform detailed whole-building energy simulations (see references). The most likely building systems requiring a simultaneous energy analysis are: the building envelope, the HVAC system, and the lighting system.

While the number of potential building system combinations can be quite large, it is impractical to assume that a poor building envelope would be combined with a high-efficient HVAC system, so you should exclude unlikely combinations of interdependent systems prior to conducting the analysis. Once various system combinations have been evaluated and the annual energy costs have been

Technique to use depends on the decision:

1) Mutually exclusive
   - Do one or the other or do nothing
   - Example: add an economizer or not
2) Independent alternatives
   - Doing one of the alternatives does not impact others
   - Example: add carpet or replace the HVAC system
3) Interdependent alternatives
   - Doing one of the alternatives does impact the others
   - Example: add lighting or increase HVAC system efficiency

Figure 7

Alternatives

calculated, an LCC analysis is performed to determine the combination of systems that yields the lowest LCC. The LCC includes the initial (first) costs for design and construction plus the operating and maintenance costs over the useful life of the building.

Procedures and examples of each of these three types of alternatives are included in later sections.

Types of Decisions

The identification of alternative constraints is important because constraints limit the economic evaluation techniques available. Economic evaluation decisions may be broadly segmented into the following five categories:

1. Accept or reject a single system or project alternative
2. Optimize the design or efficiency level of a building or building system
3. Determine the optimum building system type given multiple alternatives
4. Determine the optimum combination of interdependent building systems
5. Rank-order (prioritize) independent, competing projects with or without funding constraints

- Acceptance or rejection of one alternative
- Optimize a design, efficiency, component or system
- Determine the optimum system between multiple alternatives
- Determine the optimum combination of independent systems
- Rank the order of independent options to maximize funding

Figure 8

Types of Decisions

Defining the Project and Selecting Alternatives

The very first step of our analysis is to define the project and determine the goals of the analysis. The project may involve new construction, renovation of a building or space, upgrade of a system, or repair. As a part of our description, the criteria that need to be maintained should be identified. For example, building requirements in terms of comfort requirements, occupancy usage, energy requirements, and other variables need to be defined. Valid alternatives need to be identified based on their ability to meet these fundamental system requirements. Each alternative should be technically sound and practical for implementation.

When the system requirements have been defined, the appropriate decision type of the five above should be determined. This will allow looking at alternatives that are appropriate for that type of decision. For example, if the decision were to optimize efficiency for a new chiller system then the evaluation of rooftop units as an alternative would not be appropriate. Look at all the alternatives that can meet the decision type and the building requirements. Next, determine which of these alternatives are worthy of additional study.

Choosing the Study Period

In the building industry, construction of a house can take months and the building of a sky-scraper can take years. A decision needs to be made about when the study start date will be. It could start at the point the design process begins or it might start at the point the unit is put into service. The date selected as the starting point of the study is called the base date. This date becomes the reference point for the study. When constant dollar amounts (impacts of inflation not included) are referenced, the base date sets the reference year. This can be important if the base year starts at the start of service and the design period is very long. The base year should be documented in the study, IE: 2005 constant dollars.

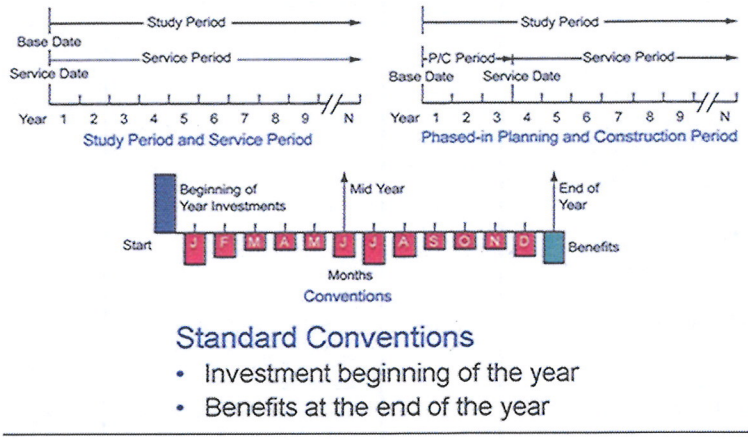


Figure 9

Study Periods and Planning Periods

A second issue to be considered is when costs and benefits will be incurred in the study year. Costs are not normally a single payment at only one point in the year. Energy costs, for example, are paid each month, so the benefit of energy savings is realized month-by-month, not just at the end of the year. To keep matters simple, it is convention to assume that investments are made at the beginning of the year and benefits are received at the end of the year. Timing conventions can be different depending on the study. The MILCON building program requires for example that benefits be calculated using a middle of the year convention. Again, this decision should be documented.

The period of time over which the economic analysis is performed will drastically affect the results. Different building components and systems have different service lives. For instance, a packaged rooftop unit typically lasts about 15 years, while a centrifugal chiller can easily remain in service for over 25 years. Figure 10 includes typical estimated service lives of various HVAC systems and components.

The life cycle period chosen is generally based on specific factors and considerations such as:

- Length of time building owner plans to retain ownership of the building
- Useful service life of building or systems
- Loan payment period
- Interest expenses
- Depreciation rules (tax effects)

Regardless of the type of investor or purpose of the cost analysis, a common life cycle period must be used when calculating present values for various design alternatives.

When the life cycle period chosen is significantly shorter than the service life of the building or systems evaluated, a realistic and accurate consideration of the project's residual (salvage) value must be considered. Failure to properly consider residual values will drastically affect the life cycle cost results.

Equipment	Median Years	Equipment	Median Years	Equipment	Median Years
Air Conditioners		Air Terminals		Air-cooled condensers	20
Window	10	Diffusers, grills, 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	Dampers	20	Base-mounded	20
Commercial air-to-air	15	Fans		Pipe-mounted	10
Commercial water-to-air	19	Centrifugal	25	Sump and well	10
Rooftop air conditioners		Axial	20	Condensate	15
Single-zone	15	Propeller	15	Reciprocating engines	20
Multi-zone	15	Ventilating roof-mounted	20	Steam turbines	30
Boilers, Hot water (steam)		Coils		Electric motors	18
Steel water tube	24(30)	DX, water, 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		

Data extracted from ASHRAE Handbook , 1999 HVAC Applications, Table 3 chapter 35

Figure 10

Estimated Service Life of Various System Components

Types of Cost

Income versus Cost-Based Analyses

It is appropriate at this time to distinguish the differences between income-based and cost-based analyses. Income-based decisions are those involving investing an amount of money over time with the goal of generating a larger sum at the end of the life cycle period. There are no appreciable costs involved, primarily income. Typical examples are calculating the rate of return for a savings account and investing for retirement. However, they could, include income from increased rents, or optimizing how many apartments to build in a given complex. For income-based investment decisions, the superior alternative will be the alternative with the greatest present value (PV).

In the HVAC industry, the majority of the economic decisions are cost-based, that is a particular system, or building component is to be upgraded or modified at a particular cost with the explicit goal of reducing future operating costs. The assumption is that investment will be recovered by the reduction in operating costs over the life of the system.

It could involve a new building where the analyst is trying to determine which system is best, or it could involve an existing facility with various upgrades being considered. For an existing facility, one of the options could simply be to *do nothing*; that is continuing as is without the modification, such as replacing single-pane windows with new double-pane windows. The existing windows may not have to be replaced, although it may be cost-effective to do so. For most cost-based HVAC decisions, the superior alternative will be the alternative with the lowest present value (PV) or lowest life cycle cost (LCC).

There are also special circumstances where implementing a particular modification or system upgrade will result in a higher net income for the building owner or tenant. For instance, remodeling a building might attract new tenants, retain existing tenants, or command a higher rental rate, offsetting the cost for remodeling. Likewise, improving the ventilation system may result in increased productivity of the employees, often offsetting most, if not all, of the required investment. These types of analyses are often a mixture of cost and income-based decisions and some may even have non-economic or qualitative considerations that must be analyzed separately.

Public Sector versus Private Sector Analyses

Before we explore how to determine cost information, we should make a few comments regarding the differences between public and private sector cost analyses.

In the public sector (government and municipalities), money for investments in buildings and equipment is obtained from tax receipts or the sale of bonds. Investment alternatives are judged based on their cost effectiveness rather than their profitability, unlike in the private sector. Public sectors do not have a true MARR (Minimum Attractive Rate of Return) because their motivations are not profit driven. The Department of Energy (DOE), Office of Management and Budget (OMB) or other municipal authority, generally establishes discount rates and cost escalation rates for public sectors. Income taxes, depreciation, insurance, and property taxes are not considered for public sector analyses. For public sectors, benchmarks such as the savings-to-investment ratio (SIR) or internal-rate-of-return (IRR) are often used.

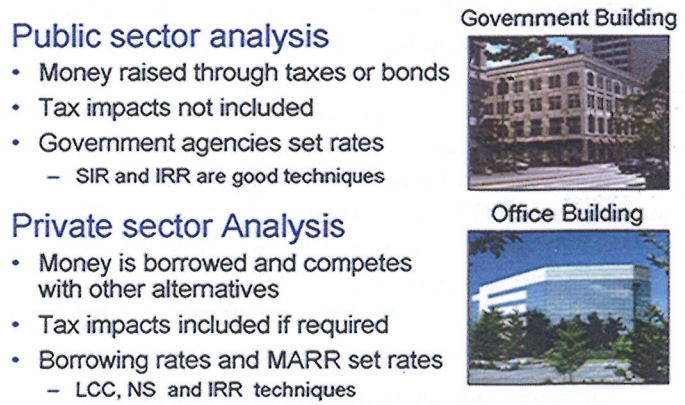


Figure 11

Public versus Private LCC Analysis

For private sector analyses, the cost of capital is of the prime considerations. In the private sector, money for investment in buildings and equipment must compete against other capital and investment opportunities available to the firm. Therefore, the rate of return is the key criteria for judging the desirability of an investment. The firm's management must establish the MARR based on alternative investments available such as stocks or bonds. Project alternatives that yield rates of return in excess of the established MARR are deemed acceptable. Income taxes, depreciation, financing, property taxes, and insurance may all be considered for a private sector cost analysis. For private sectors benchmarks such as life cycle cost (LCC), Net Savings (NS), and internal rate of return (IRR) are often used.

Analysis Techniques

This section discusses the primary economic inputs required for a life cycle cost analysis. These include the discount rate, and the way to handle inflation and cost escalation. It is also important to understand the basic concept of how costs are calculated to account for the time value of money as either present sums or future sums.

Detailed descriptions of the economic formulas for calculating single payment and uniform series payments of present or future sums are included in the Appendix. In this section, each formula is described with an example, if you are not familiar with the formula or their usage you should review this before proceeding. Equations marked with an "A" designate an equation from this section.

Discount Rate

Real and Nominal Rates

Real rate neglects inflation; the costs are in constant dollars (same dollars in all study years). Nominal rate includes inflation and dollars are in current dollars (dollar value changes with each year of the study).

Earlier it was pointed out that monetary transactions have a time value. This time value is expressed as an interest rate. When the interest rate reflects a payment to the investor for using his money resulting in an increase in value it is compounding. This is the situation for investments like a savings account or CD account where you are the investor. If the investor is a lending institution, the institution determines the interest rate. Not all investors in buildings are lending institutions. In many building situations, the interest rate is based on the investor's loss of opportunity to invest in another project. This is discounting. This rate may be much different from the rate charge by a lending institution. The rate of interest in both cases reflects the investor's time value of money. Depending on the investor this can vary considerably. In fact, the rate may vary with the same investor based on the risk of the project. The rate used reflects this time value of money (or opportunity cost). It is used in discount formulas or selecting discount factors used to convert ("discount") cash flows to a common time. In the private sector, the discount rate used is comparable to the rate of return available for alternative benchmark investments, sometimes referred to as the minimum attractive rate of return, or MARR.

There are two types of discount rates used in life cycle economics. The real discount rate is essentially an interest rate used to convert all future cash flows to present value (PV) terms, neglecting inflation. It is referred to as real because future costs are expressed in constant dollars, neglecting inflation. The other is the nominal rate that includes the impact of inflation and the dollars are said to be in current dollars.

Once the calculations are complete, the results may be compared to those of the benchmark investment to determine which alternative is the most cost-effective. Depending on the investor's risk tolerance and the investment duration, the discount rate used could be equivalent to the interest rate for bank certificates of deposit (CDs), government T-bills, bonds, stocks, or other alternative investments.

For public sector cost studies, such as federal government or municipally owned buildings, the discount rate used is set by the U. S. Department of Energy (DOE) or Office of Management and Budget (OMB). Public sector economic studies are exclusive of tax consequences. Federal discount rates are published each year by the appropriate government agency.

Minimum Attractive Rate of Return (MARR) is the lowest acceptable rate of return on an investment as determined by the investor. A building owner typically makes capital budgeting decisions based on a fixed amount of available capital. This fixed amount of available capital is competed for by various alternative investments. For example, should the owner invest in higher-efficient HVAC equipment or upgrade the building lighting system to higher-efficient ballasts and lighting fixtures, or should the building owner take this same amount of capital and invest it into marketable securities such as stocks or bonds? The building owner or cost analyst must decide the MARR for any proposed capital expenditure. Proposals that meet or exceed the MARR are acceptable.

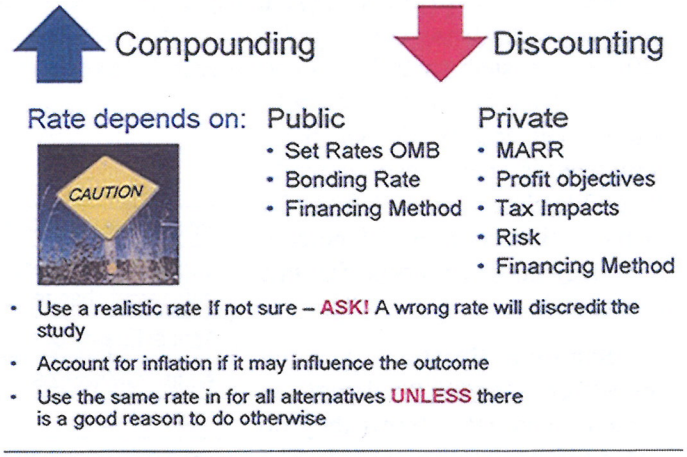


Figure 12

Discount Rates and Minimum Attractive Rate of Return (MARR)

Future Value (Compounding)

There are two ways of brining costs to a common point using the time value of money. They can be brought to an equivalent value in the future by compounding the interest or they can be discounted by the interest to determine an equivalent amount in the present.

The future value *(FV)* of a present sum of money *(PV)* may be determined using formulas A1 for a single payment or A3 for a uniform series of payments. When the amount of uniform payments that will equal a future sum is needed, formula A4 is used. Compounding occurs when the original principal amount is invested at an interest rate for a period of time. The total amount accumulated at the end of the investment period consists of the original principal amount plus accrued interest.

Present Value (Discounting)

As described earlier for LCC analysis the convention is to bring future costs and benefits to the present value. To determine the value in today's dollars (present value) of a future amount of money a similar concept called *discounting* is used. Discounting is actually the reverse of compounding. With discounting, all costs incurred over the life of the system are converted to a common point in time for comparison, usually the beginning of the study period. This is referred to as the Present Value (PV). To determine the present value of a single future sum equation A2 can be used. When uniform series of cash flows needs to be converted to a single present worth value equation A5 is used and equation A6 can be used to determine the uniform amount necessary to equal a present value sum. Costs are not always uniform over the life cycle, equation A7 can be used to calculate the present value when costs are escalating.

The present worth formula will be used extensively in the rest of this TDP to bring future costs and benefits to a present dollar value.

Let's use the equations to illustrate the concept of Present Value (PV) in the following example problem.

Example 1: An HVAC system replacement is being performed on an existing building. Two alternatives are being considered: a standard-efficiency system (with R-22 refrigerant) and a high-efficiency system (with R-134a refrigerant). Given the cost data indicated in Figure 13, calculate the life cycle cost (LCC) of both alternatives and decide which alternative is most economically favorable. Use a study life of 20 years, a discount rate of 8 percent and neglect water costs for this example.

	Standard-Efficiency (Base Case)	High-Efficiency (Alt. 1)
Initial Investment Cost	$80,000	$100,000
Capital Replacement Cost (refrigerant change-out year 6)	$20,000	$0
Annual Energy Cost	$15,000	$10,000
Annual OM&R Cost	$5,000	$6,000
Residual Value	($2,000)	($2,500)

Figure 13

Cost Data for Example 1

Solution: Because the initial investment costs are already in present value (PV) terms they do not need to be discounted. The Capital Replacement Cost for the standard refrigerant in year six for the Base Case must be discounted using Equation A2. Alternate 1 uses a newer refrigerant that is not subject to the phase-out schedule. Annual recurring costs must be discounted using the UPV formula, Equation A5. Notice that the residual value is a negative number (benefit), which is deducted from the costs. Figure 14 includes all cost data discounted to present values (PV) as appropriate:

	Standard-Efficiency (Base Case)	High-Efficiency (Alt. 1)
Initial Investment Cost [already in PV]	$80,000	$100,000
Capital Replacement Cost (refrigerant change-out yr. 6) [Eq. A2, N = 6]	$12,603	$0
PV of Annual Energy Cost [Eq. A5, N = 20]	$147,272	$98,181
PV of Annual OM&R Cost [Eq. A5, N = 20]	$49,091	$58,909
PV of Residual Value [Eq. A2, N = 20]	($429)	($536)
Total (PV) LCC	**$288,537**	**$256,554**

Figure 14

Example LCC Calculation

Alternate 1, the high-efficiency system, has a lower life cycle cost (LCC); therefore, it is the preferred alternative.

When performing these types of analyses, be careful that you do not confuse present value costs with present value savings. When costs are the predominant consideration, as illustrated in Example 1, the alternative with the lowest PV or life cycle cost is preferred. With income-based problems, the alternative that yields the greatest present worth savings amount is preferred.

In this example notice that we assumed that all annual (recurring) costs remained constant each year. In reality this is incorrect. However, if both alternatives are compared using identical assumptions then the results should be reliable and comparable. To be more precise, recurring or future costs should be adjusted to account for the effects of inflation, or the impacts of cost escalation.

Inflation

Inflation is a decrease in the value of money due to an increase in the costs of goods and services in the overall economy. Because LCC studies are done covering long periods of time inflationary affects change the value of the dollar. This inflationary affect has the impact of reducing the effective discount rate.

There are two methods of dealing with inflationary affects. First, the discount rate used is based on a rate that includes the inflation rate; this rate is called the nominal discount rate, *r*. When nominal discount rate is used, the value of dollars is in current dollars reflecting the inflationary impact. The second method is to use the actual or real discount rate, *i* costs with this method are expressed in constant dollars.

To illustrate, suppose the real discount rate, *i* is 7.0 percent and the general price inflation rate, I is 3.0 percent, solving Equation A8 yields a nominal discount rate of 3.9 percent, or about 4.0 percent. For rough approximations, you can simply add or subtract the general rate of inflation, I to the appropriate discount rate used. Using either the real or the nominal discount rates will yield identical present values as long as you use consistent discount rates for all calculations.

The current dollar method using the nominal discount rate, r is generally more appropriate for private sector analyses dealing with the effects of taxes. Regardless of which type of analysis you are performing, public or private, it is important that you use a realistic and consistent discount rate for all alternatives as this will have a dramatic effect on the results and unrealistic rates will discredit the results.

Cost Escalation, *e*

The prices of goods and services generally increase over time. The rate of increase in costs (such as equipment, electricity or labor) over time is referred to as the escalation rate, *e* and represents the amount of change per period, *N*.

In the last section, we discussed the present value (PV) of a uniform series of payments. For those examples, we assumed that the annual amounts, *A* remained constant each year over the life cycle period. In reality, this is a simplistic and unrealistic assumption; however, it was done to illustrate the concept of discounting. In order to select an accurate escalation rate for an economic analysis we would need to use a crystal ball. Since this is not possible, the best method we have is to use the past as an indicator of future cost escalation, however unforeseen geopolitical circumstances can lead to rapid and dramatic changes in costs over short periods or time. The historical, long-term cost escalation rate for goods and services has averaged somewhere around 2-3 percent. However, prices for energy (natural gas, fuel oil, etc.) tend to be much more volatile and fluctuate more frequently and more rapidly than the costs for labor and materials. You may recall the energy shortage in California in the late 1990s. During that period, the cost of electricity doubled or tripled over a very short time. In addition, the cost of natural gas has increased, at a rate greater than the overall rate of inflation, over the past several years.

You should select an escalation rate that you can justify with documentation from economic sources such as the U.S. Department of Commerce or other governing authority.

Let's review the effects of compounding, as it pertains to cost escalation, with an example.

Example 2: Suppose electricity costs $0.10/kWh today and escalates at a rate of 5 percent per year. What will be the cost of electricity in 10 years?

We use our future value (FV) formula (Eq.A1) and substitute the escalation rate, *e* for the interest rate, *i* as follows:

$$FV = PV(1 + I)^N = \$0.10(1 + 0.05)^{10} = \$0.163 \text{ kWh}$$

The cost of utilities represents a good case of the need to account for cost escalation. These costs are normally not one-time changes but rather yearly changes to an annual payment. Let's use another example to demonstrate how to deal with annual cost escalation.

Example 3: A building owner is currently paying $20,000 annually for power. If the cost of electricity escalates at a 4 percent annual rate and the owner's discount (MARR) rate is 10 percent, what is the PV assuming N=20 years?

Substituting the known values into our equation:

$$UPV^* = \$20{,}000 * \left(\frac{1+0.04}{0.10-0.04}\right) * \left[1-\left(\frac{1+0.04}{1+0.10}\right)^{20}\right] = \$233{,}759$$

Cash Flow

In most situations monetary transactions are not one-time events but rather a series of costs and benefits. This stream of income and outflow of cash is referred to as a cash flow. It is often convenient to diagram these flows as shown in Figure 15. A cash flow is a list of year-by-year costs for a design case. For each year the cash flow is calculated as:

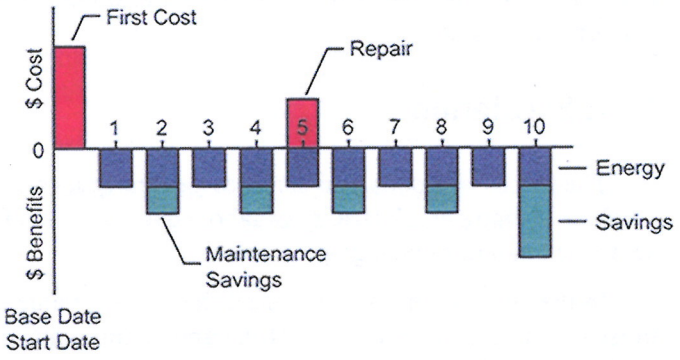


Figure 15

Cash Flow Convention

Cash Flow =

Cash investment costs + Down payments for investment loans

+ Loan principal and interest payments – Benefits + Annual operating costs

+ Non-annual operating costs

Using this sign convention, a positive cash flow value indicates a cost while a negative value indicates a benefit.

Initially the cash flow is calculated in actual value terms. These are the actual amounts of money required to pay costs at the time they occur. Therefore, these costs include the effects of cost escalation, but do not include present worth discounting.

When performing a private sector analysis that includes income taxes, there are two types of cash flows. One is the cash flow before considering taxes that is called the Before Tax Cash Flow (BTCF). The second cash flow, referred to as the After Tax Cash Flow (ATCF), includes taxes.

Cash flow analysis is helpful in revealing the years in which the outflow of cash to maintain the investment is not exceeded by the benefits derived from the alternative.

Economic Factor Tables

This publication uses formulas to determine economic cost values. In lieu of solving the equations, published tables of economic factors can be used to determine a multiplier to be used with the known value to determine the required preset or future value. These tables can be found in numerous textbooks on engineering economics. Formulas are used in this text to illustrate the concepts and because most calculations are done today using electronic spreadsheets or computer programs. These calculation tools are demonstrated later in this text.

Collecting Data

Before looking for where to obtain the data, a few comments are in order about costs. First, remember that the goal of LCC analysis is making a decision between alternatives. This means it is not necessary or even desirable to include each cost associated with the project. When the alternatives have been identified, look at each and determine what cost items need to be included. Any cost item that is the same for all the alternatives can be ignored. Second, determine if the cost item is significant and will impact the outcome of the study. For example if two air handlers are being evaluated that require different belts with a cost difference of $3 and the belts will be changed three times during the study period, but the energy difference is $800, the belts should be ignored. A second consideration is some costs are spent or committed to at the time of the study. These costs are called sunk costs and should not be included in a study.

Cost Estimating

The most time-consuming task of performing an economic analysis is usually compiling all pertinent cost-related data. Costs are divided into two categories: investment costs and operating costs. Typical investment costs occur at the beginning of the study period while operating costs are generally recurring, annual expenses. The following sections offer some guidelines as to where to find values for each of the cost and benefit associated with a project.

Investment Costs

Typical investment costs include: first cost (planning, design and construction, including the purchase of equipment and installation labor), and residual values (salvage or resale value less any disposal costs). Residual value may also be negative if disposal costs are involved.

Investment costs also include utility rebates (demand-side manage-ment), taxes, and financing. Non-monetary costs and benefits (e.g., aesthetics, improved comfort, IAQ, occupant productivity, retaining tenants, and acoustics) that can result in increased rents or property value can be included.

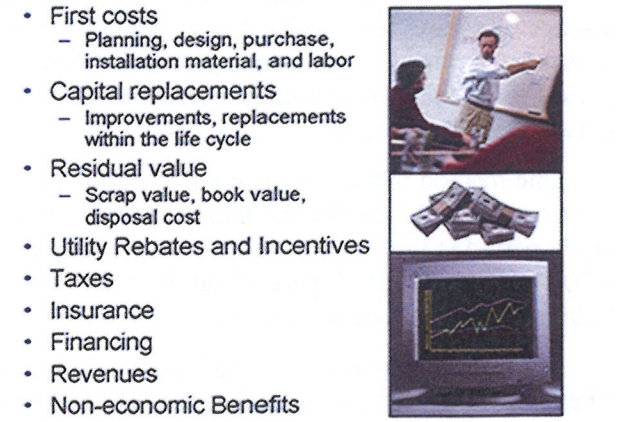


Figure 16

Investment Costs

First Cost

First cost is the all the costs associated with the design, purchase, and installation of the alternative to have it ready for first service. First costs are the easiest to determine. Because the cost occur close to the start of the project inflation and uncertainty influences are minimized. Many source of data are also readily available to estimate costs, the reference section in the appendix lists several of these sources. Sources like RS Means are available that can be used to determine costs based on national averages. When the design is in the early stages these sources are recommended since the information required to obtain detailed cost estimates are not yet available.

In most studies, the first cost is assumed to occur at the start of the first year and is the sum of all investment items. If an investment item is financed with a loan, the entire investment is included in the first cost even though only the down payment for the loan will actually be paid at the beginning of the first year.

It is recommended that the same sources be used for all alternatives when calculating first costs because many assumptions are built into the cost.

Capital Replacement Costs

Capital replacements are costs to replace major system components, incurred at a future date, during the analysis period (e.g., refrigerant phase-out or replacement of a unit). These costs are paid out of the capital budget, and are not considered part of the annual operating expenses. The best way to determine these costs is to use the same sources as recommended for first cost and then adjust the cost for the year in which it occurs. This method is used when the replacement value is already in present value terms. Escalation of these costs should be considered when the value is based on the current present value.

If the service life of a unit is less that the study period then the unit needs to be replaced as part of the study. The cost of a unit replacement can be considered a capital replacement cost.

Residual Value

At the end of the study period, the system has value. This value is sometimes called the salvage value which is somewhat misleading because the value is normally far in excess of the scrap value of system. The service life of equipment is often longer that the study period. Figure 11 presented service life of various pieces of HVAC equipment. If the value at the end of the study period is not fairly dealt with, the study results may be misleading. There are a number of ways to determine residual value.

One method that can be applied to public projects is the straight-line method. In this method, the first cost is divided by the number of year in the service life and the value left at the end of the study period is the residual value. As an example an evaporative condenser that cost $20,000 has a 20-year service life (Figure 11) at the end of a 15-year study its value is $2,500. ($10,000 / 20 = $500 per year, at the end of the study 5 years remain at $500 or $2,500)

A second method useful in private analysis is the book value at the end of the study period. The book value is the amount that has not yet been depreciated. If the type of depreciation used is known for the study then it is easy to determine the book value at the end of the study period. If it is not know the use of the double declining method is a good approximation. Deprecation is covered in the Special Topics section of this TDP.

Other methods of determining the residual value can be based on the resale value of the building and the part represented by the system or conversion cost or scrap value. Take care to not over estimate the residual value, as it will influence the credibility of the study. In many studies particularly if it is for similar systems and the study period is long the residual value is ignored. Residual value is more important when the study period is short or the equipment has recently been replaced to match study period to service life.

One final word of caution on residual value, with some HVAC components there is a charge for decommission and scraping the system (refrigerants and oils for example). If the difference is significant between alternatives, the disposal cost should be included. Residual value is a positive cash flow and disposal is a negative cost reducing the residual value.

As a rule of thumb:

- One quick method of setting a value is to prorate the initial cost
- For example a $10,000 unit with a 15 year life at the end of 8 years would be $10,000 x (8/15) = $5,333/year
- Another method is to assume double declining depreciation for the IRS allowed years and then use the book value at the end of the study period

Figure 17

Methods of Determining Residual Value

Utility Rebates and Incentives

Utility companies offer rebates to help reduce system demand that requires the construction of larger power plants and transmission lines. Rebates are offered for installing high efficiency units to help with this demand side management. These rebates may be offered as one-time payment during the startup year or as a payment over a period of time. If the rebate is a one-time payment during the startup year, it is treated as a positive cash flow reducing the first cost. When the rebate is offered over a period of time than it should be treated as positive cash flow in the years when it applies. If the rebate is offered, as a reduction in electric cost for a period of time then the benefit should be added to the benefit from power savings.

Other types of utility incentives are sometimes offered for things like fuel switching and the use of green power. These incentives may also be one-time payments, reduced financing rates or utility rate adjustments. This is also true for some on-site power systems and the use of renewable energy. All of these items can be accounted for in LCC studies by applying them to the appropriate cost items. If the incentive is a one-time or fixed interval cost apply the benefit as a positive cash flow to the investment costs. If the incentive is a reduction in energy costs apply the credit to the operating costs, and if it involves financing options apply it to the loan calculation. In some cases such as green power, the cost may be a premium rather than a credit.

Taxes

Investment and operating costs influence the size of income taxes paid by the building owners. Therefore, income taxes are another cost component that should be considered in a private sector lifecycle analysis. Adding income tax to the before tax cash flow produces an after tax cash flow (ATCF) which is the basis for subsequent internal rate of return and net present worth calculations. In this section, the calculation of income tax and the ATCF will be discussed.

Income tax is computed as follows:

Equation 2

$$\text{Tax} = \text{Tax Rate} * \text{Taxable Income}$$

and

$$\text{Taxable Income} = \text{Income} - E_{ABE} - D - I$$

Where:

Income_T = Total Income

E_{ABE} = Allowable Business Expense

D = Deprecation for the year

I = Interest paid on loans

As an example, suppose we are studying the lifecycle costs of two alternate HVAC system designs for a restaurant. The total income of the firm owning the restaurant would be money received from the sales of meals. Allowable business expenses would include salary and benefits for employees, the cost of food used to prepare the meals, costs for maintenance of equipment, and utility costs (electricity, gas, water). When examining this list of income and expense items, however, we immediately find a problem. In analyses performed for most HVAC studies, we typically do not have information about many of these items such as total income or salary and benefits. Further, these items are beyond the scope of the HVAC system analysis we are typically conducting.

Fortunately, this is not a major problem. In LCC studies, we are interested in comparative costs between the design cases being studied, not absolute costs. Second, regardless of which design case is chosen, the unknown income and cost components will remain constant. When considering the income tax difference between two design cases, all these unknown income and cost components will cancel with each other. Therefore, considering only the known income and allowable business expenses is acceptable because it will still yield accurate comparative results.

Due to this situation, we are really calculating the partial taxable income and the partial income tax for a design case. Partial taxable income is calculated as:

Equation 3

$$\text{Partial Taxable Income} = \text{Income}_{TK} - E_{ABEK} - D_A - I_A$$

Where:

Income_{TK} = Sum of investment items that are benefits (negative values) and are not identified as tax-exempt.

E_{ABETK} = Sum of cash investments, down payments and loan principal payments for the year, but only if the investment item is not depreciated

D = Total depreciation charge for investments subject to depreciation

I = Total interest charge for investment loans

The partial income tax is calculated as:

Partial Income Tax = Tax Rate * Partial Taxable Income

A few notes about this method:

- Net Income is {Income} – {Allowable Business Expenses} described above. In most HVAC and building design studies more expense, components are known than income components. Therefore, "Net Income" is usually a negative value.
- Depreciation is the total depreciation charge for the year, in question and interest is the total interest charge for the same year.
- Taxable Income is the partial taxable income described above: {Net Income} – {Depreciation} – {Interest}. Because most of the known components in HVAC and building design studies are costs, taxable income is usually a negative value.
- Tax is the partial income tax. Again, because Taxable Income is often a negative quantity, the partial income tax will be negative. By itself, a negative tax value is not meaningful. In our normal experience, tax is always a positive quantity that must be paid to the government. It is important to recognize that a negative tax quantity does not mean that the government is paying the owner money. Rather, because this is a partial tax quantity, it is only meaningful when compared with the partial tax for another design case to determine whether tax payments of one case are larger or smaller than another.

After tax cash flow is the cash flow with the partial income tax included:

After Tax Cash Flow = Before Tax Cash Flow + Income Tax

Insurance

Buildings carry insurance not only for fire risk but also in some cases for loss of service. In some studies, the insurance rate charged for one alternative may be different that the rate charged for another alternative. This is particularly true when the system is used for a critical application or is a technology with inherent risk because of the material used or the technology. If this is the case, the difference in insurance premiums can be added into the LCC study as a reoccurring annual cost.

Finance Costs

The first costs of most projects are financed in some fashion. If the study is to include financing charges, a few concepts need to be understood to apply the information in a LCC study.

If an investment item is not financed with a loan, then it is a cash investment. If this is the case, the full investment cost will be paid in the "year incurred," normally the beginning of the first year. Therefore, the actual value investment cost will be incorporated into the cash flow in the "year incurred."

If an investment item is financed with a loan, then only the down payment will be paid in the "year incurred." The remainder of the investment cost is loan principal that will be repaid along with interest payments over the term of the loan. The down payment and principal portions of the investment are calculated as:

Equation 4

$$P = I * \left(\frac{F}{100} \right)$$

and:

$$DP = I - P$$

Where:

DP = Down payment amount
F = Percent of total investment cost that is financed
I = Actual value of investment cost at the time it occurs
P = Loan principal

Example 4: The actual cost for HVAC equipment is $100,000. 70 percent of this cost will be financed with a loan. Therefore, the principal is $100,000 * (70/100) = $70,000 and the down payment is $30,000.

The financed amount is repaid using one of three methods.

First, if a financed investment is repaid using the equal payments plan, principal and interest payments are calculated such that equal end-of-year payments are made. The annual loan payment is calculated using Equation A6 as:

$$A = P * \frac{\left(i * (1+i)^N \right)}{\left((1+i)^N - 1 \right)}$$

In order to determine the interest and principal payments for each year, the following equations are used:

$$Ai_Y = i * RP$$

$$AP_Y = A - Ai_Y$$

Where:

A = Annual end-of-year loan payment
Ai_Y = Interest component of the loan payment for year y
AP_Y = Principal component of the loan payment for year y
I = Effective annual interest rate for loan, percent per year in decimal format (e.g., 0.10 instead of 10 percent)
P = Loan principal
RP = Remaining loan principal at the end of the previous year
N = Term of loan in years

Example 5: A loan principal of $10,000 is repaid using the equal payments plan. The term of the loan is 5 years and the effective annual interest rate is 10 percent per year. Loan payments are shown in Table 1:

Table 1

Year	Loan ($)	Payment ($)	Interest Principal ($)	Remaining Principal ($)
0	0	0	0	10,000
1	2,638	1,000	1,638	8,362
2	2,638	836	1,802	6,560
3	2,638	656	1,982	4,578
4	2,638	458	2,180	2,398
5	2,638	240	2,398	0
Totals	$13,190	$3,190	$10,000	-

Second, if a financed investment is repaid using the interest only payments plan, principal is not repaid until the final year of the loan. During each year of the loan, interest is paid on the principal. Annual interest payments are calculated as:

$$A_Y = Ai_Y = i * P$$

In the final year of the loan the normal interest payment is made and the principal is repaid:

$$Ai_Y = I * P$$

$$AP_Y = P$$

$$AP_N = AP_Y + Ai_Y$$

Where:

- Ay = Total loan payment for year y
- Ai_Y = Interest component of the loan payment for year y
- AP_Y = Principal component of the loan payment for year y
- I = Effective annual interest rate for loan, percent per year in decimal format (e.g., 0.10 instead of 10 percent)
- P = Loan principal

Example 6: A loan principal of $10,000 is repaid using the interest only plan. The term of the loan is 5 years and the effective annual interest rate is 10 percent per year. Loan payments are shown in Table 2:

Table 2

Year	Loan ($)	Payment ($)	Interest Principal ($)	Remaining Principal ($)
0	0	0	0	10,000
1	1,000	1,000	0	10,000
2	1,000	1,000	0	10,000
3	1,000	1,000	0	10,000
4	1,000	1,000	0	10,000
5	11,000	1,000	10,000	0
Totals	$15,000	$5,000	$10,000	-

Third, if a financed investment is repaid using the equal principal payments plan, equal amounts of the loan principal are paid at the end of each year. Interest on the remaining principal is also paid each year. Annual loan payments are calculated as follows:

$$Ai_Y = i * RP$$

$$AP_Y = \frac{P}{N}$$

$$A_Y = AP_Y + Ai_Y$$

Where:

A_Y = Total loan payment for year y

Ai_Y = Interest component of the loan payment for year y

AP_Y = Principal component of the loan payment for year y

I = Effective annual interest rate for loan, percent per year in decimal format (e.g., 0.10 instead of 10 percent)

P = Loan principal

RP = Remaining loan principal at the end of the previous year

N = Term of loan in years

Example 7: A loan principal of $10,000 is repaid using the equal principal payments plan. The term of the loan is 5 years and the effective annual interest rate is 10 percent per year. Loan payments are shown in Table 3:

Table 3

Year	Loan ($)	Payment ($)	Interest Principal ($)	Remaining Principal ($)
0	0	0	0	10,000
1	3,000	1,000	2,000	8,000
2	2,800	800	2,000	6,000
3	2,600	600	2,000	4,000
4	2,400	400	2,000	2,000
5	2,200	200	2,000	0
Totals	$413,000	$43,000	$410,000	-

Revenues

LCC analysis is normally used to evaluate the savings generated by an alternative over a base system and not to evaluate income-producing decisions. Decision methods such as the break-even or rate of return method are normally used when evaluating income producing. However, in some LCC studies one alternative may increase the rental income. This may be the result of a more comfortable environment, better productivity or a more desirable rental property. The impact of increased revenues can be accounted for in a LCC study by adding the difference as a positive cash flow through a positive annual reoccurring cost.

Non-Economic Benefit

Non-monetary costs are typically qualitative rather than quantitative factors and may be difficult to analyze. Industry research has shown that tenant (occupant) productivity levels increase with improved indoor comfort levels. Incremental system costs for installing high-quality HVAC systems (e.g., zoning systems, VAV, linear slot air diffusers, etc.) are quickly recovered by improvements in tenant productivity levels. A white paper titled, "Predicting Costs Associated with Uncomfortable Tenants - *Understanding How the Indoor Environment Affects Productivity"* is available from Carrier and covers this concept in detail. In addition, a spreadsheet program is available to perform these calculations (see special topics section).

Research has shown that *a 1 percent improvement in tenant productivity will completely offset the entire energy costs of a typical office building*. A general rule of thumb is: employees cost $200/ft^2; rent costs $20/ft^2 and utilities cost $2/ft^2. This means that employees cost 100 times more than the utilities; therefore, a small increase in comfort levels (productivity) yields a large return on investment (ROI) and a quick payback.

Operating and Maintenance Costs

The more difficult part of determining costs is the determination of the annual costs to operate the system. These costs are also the ones that generate the savings to pay for higher investment costs. Operating and maintenance costs include the costs of all utilities, costs for regular maintenance, service contracts, operating labor, and expendable supplies replaced at regular

intervals. Remember, that if the alternatives are the same there is no need to include these items in the analysis. For example, if the cooling efficiency of two gas fired rooftop units is the purpose of the study and they have the same heating efficiency, it is not necessary to calculate the gas heating costs.

It is generally desirable to obtain these costs locally from vendors, contractors, and utilities; however, numerous sources of cost data exist, some of which are listed in Additional Resources.

Annual energy consumption values are the most difficult costs to obtain determining the annual energy costs is also one of the most important steps in LCC studies. As was pointed out before for some studies the calculation can be done with simple hand calculations, like the full load operating hours of a motor. However, most studies will require more extensive evaluation of energy costs. Computer software programs such as Carrier's HAP (Hourly Analysis Program) and *EnergyPlus* (U. S. Dept. of Energy) are commonly used to calculate annual energy costs.

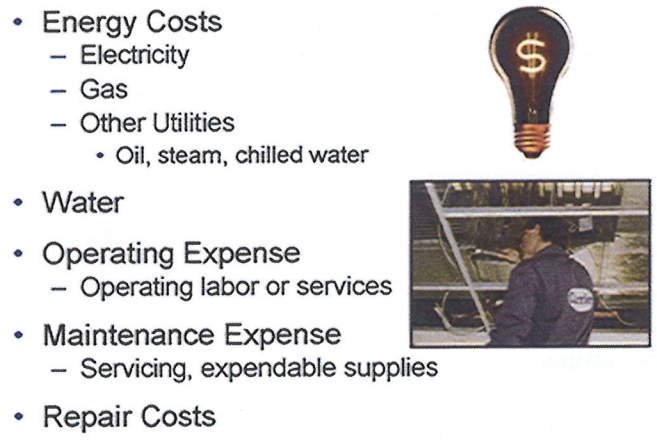


Figure 18

Elements of Operating and Maintenance Costs

Electric Energy Costs

Electricity is required on almost all projects. Electric utility rates are also one of the most complicated things to calculate. Individual utility companies charge for energy use, fuel use and demand in widely different ways and use vastly different terminology in stating their pricing structures. This presents a challenge for developing one consistent approach to calculating utility costs. Carrier's HAP and many other energy analysis programs use a modular approach to meet this challenge. The information in this section reflects how the HAP program deals with utility rate structures. The information provides guidance about the rate structure information required and an approach on how to calculate the electric utility costs regardless of the actual calculation tool. In some studies, the demand may be as important as the usage costs so it is imperative that the rate structure be properly applied. The HAP program provides building blocks representing the common billing mechanisms for energy, demand, demand determination, and miscellaneous charges. The user is able to choose among these building blocks to assemble a utility rate model that best represents the pricing structure used for their building. The following sections explain how to apply these features to define electric and fuel rates.

An "energy charge" is the component of the electric bill that charges for energy consumption measured in kWh. Nearly all utility rates include an energy or fuel charge; many include nothing but an energy or fuel charge.

Electric usage charges are usually one of five types of structure:

Flat Price

This pricing structure uses a flat cost/kWh price for all times, or specific periods such as seasons or time-of-day periods.

Sample Utility Rate Statement:

All kWh during summer billing months 0.077 $/kWh

All kWh during winter billing months 0.049 $/kWh

Example 8: During one summer billing month 40,000 kWh is used. The energy charge is calculated as:

kWh Range	Block Size	*	Price	=	Cost
All	40,000 kWh	*	0.077 $/kWh	=	$3,080
Total Energy Charge				=	$3,080

Declining Block

This pricing structure uses different energy or fuel prices for different "blocks" of energy or fuel that are consumed. Generally, the price declines with each succeeding block, hence the name "declining block."

Sample Utility Rate Statement:

For the first 8000 kWh	0.101 $/kWh
For the next 15000 kWh	0.063 $/kWh
For all remaining kWh	0.044 $/kWh

Example 9: During one billing month 40000 kWh is used. The energy charge is calculated as:

kWh Range	Block Size	*	Price	=	Cost
1-8,000	8,000 kWh	*	0.101 $/kWh	=	$808
8,001-23,000	15,000 kWh	*	0.063 $/kWh	=	$945
23,001-40,000	17,000 kWh	*	0.044 $/kWh	=	$748
Total Energy Charge				=	$2,501

Demand Block

This pricing structure is the same as "Declining Block" above, except that the block sizes vary each month based on the billing demand for that month. Therefore, the block sizes have units of energy/demand such as kWh/kW. In some cases the units are referred to as "hours use." This pricing structure is rarely seen for fuel charges.

Sample Utility Rate Statement:

For the first 150 kWh/kW demand	0.085 $/kWh
For the next 100 kWh/kW demand	0.062 $/kWh
For all additional kWh	0.038 $/kWh

Example 10: During one billing month the billing demand is 200 kW and 60000 kWh is used. The energy charge is calculated as:

kWh Range	Block Size	*	Price	=	Cost
1-30,000	30,000 kWh	*	0.085 $/kWh	=	$2,550
30,001-50,000	20,000 kWh	*	0.062 $/kWh	=	$1,240
50,001-60,000	10,000 kWh	*	0.038 $/kWh	=	$380
Total Energy Charge				=	$4,170

Mixed Block

The "mixed block" charge combines elements of both "declining block" and "demand block." It contains a mixture of blocks of fixed size and blocks with size varying based on billing demand. Therefore, in an electric rate, some blocks have kWh units and others have units of kWh/kW or "hours use." This pricing structure is sometimes used for electric energy charges but is uncommon for fuel charges.

Sample Utility Rate Statement:

For the first 150 kWh/kW demand	0.075 $/kWh
For the next 15,000 kWh	0.050 $/kWh
For the next 100 kWh/kW demand	0.047 $/kWh
For all additional kWh	0.042 $/kWh

Example 11: During one billing month the billing, demand is 120 kW and 50,000 kWh is used. The energy charge is calculated as:

kWh Range	Block Size	*	Price	=	Cost
1-18,000	18,000 kWh	*	0.075 $/kWh	=	$1,350
18,001-33,000	15,000 kWh	*	0.050 $/kWh	=	$750
33,001-45,000	12,000 kWh	*	0.047 $/kWh	=	$564
45,001-50,000	5,000 kWh	*	0.042 $/kWh	=	$210
Total Energy Charge				=	$2,874

Compound Block

The "compound block" charge uses a two-tier block structure shown in the example below. The first tier contains demand blocks that are used with the billing demand each month to establish a series of large energy blocks. These first tier blocks are subdivided into smaller energy blocks each with a separate price. Compound Block charges are infrequently seen in electric rate structures.

Sample Utility Rate Statement:

For the first 125 kWh/kW demand	
For the first 3,000 kWh	0.087 $/kWh
For the next 87,000 kWh	0.043 $/kWh
For the all additional kWh	0.034 $/kWh

For the next 200 kWh/kW demand

For the first 6,000 kWh	0.060 $/kWh
For the next 85,000 kWh	0.044 $/kWh
For the all additional kWh	0.042 $/kWh

For all over 325 kWh/kW demand

For all kWh	0.039 $/kWh

Example 12: During one billing month the billing, demand is 500 kW and 200,000 kWh is used. The energy charge is calculated as:

kWh Range	Block Size	*	Price	=	Cost
First 125kWh/kW	62,500 kWh				
1-3,000	3,000 kWh	*	0.087 $/kWh	=	$261.00
3,001-62,500	59,500 kWh	*	0.043 $/kWh	=	$2,558.50
Next 200kWh/kW	100,000 kWh				
1-6,000	6,000 kWh	*	0.060 $/kWh	=	$360.00
6,001-100,000	94,000 kWh	*	0.044 $/kWh	=	$4,136.00
All Above 325kWh/kW	37,500 kWh				
1-37,500	37,500 kWh	*	0.039 $/kWh	=	$1,462.50
Total Energy Charge				=	$8,778.00

A "demand charge" is imposed for the peak power use during a month rather than for total energy consumption. Utility companies typically impose a demand charge in addition to the energy charge. While nearly all electric and fuel rate structures contain an energy or fuel charge, only certain rates include a demand charge. Demand charges are simpler than energy charges in that there are only two types. Each is described below:

Flat Price

This demand charge structure uses a flat cost/demand price for all times, or specific periods such as seasons or time-of-day periods.

Sample Utility Rate Statement:

All kW of on-peak demand during summer months	10.45 $/kW
All kW of mid-peak demand during summer months	8.65 $/kW
All kW of on-peak demand during winter months	7.40 $/kW

Example 13: During one summer billing month the demand for on-peak hours is 370 kW and demand for mid-peak hours is 207 kW. The demand charge is calculated as:

kW Range	Block Size	*	Price	=	Cost
All	370 kW	*	10.45	=	$3,866.50
All	207 kW	*	8.65	=	$1,790.55
Total Demand Charge				=	$5,657.05

Stepped

This pricing structure uses different demand prices for successive "blocks" of demand. This pricing structure is similar to the declining block energy charge.

Sample Utility Rate Statement:

For the first 50 kW of billing demand	10.18 $/kW
For the next 100 kW of billing demand	7.00 $/kW
For all remaining billing demand	5.44 $/kW

Example 14: During one billing month the billing demand is 400 kW. The demand charge is calculated as:

kW Range	Block Size	*	Price	=	Cost
1-50	50 kW	*	10.18 $/kW	=	$509
51-150	100 kW	*	7.00 $/kW	=	$700
151-400	250 kW	*	5.44 $/kW	=	$1,360
Total Demand Charge				=	$2,569

Whenever demand charges or demand block energy charges are used in a rate structure, the peak demand must be determined for each billing period. For electric rates the integrated power use over a 15, 30, or 60-minute period is typically used. For fuel rates, the peak hourly fuel consumption, or peak daily fuel consumption is used. In the simplest cases, the measured peak demand is used directly to compute the demand charge. In other cases, however, the measured demand is adjusted by one or more clauses to determine a "billing" demand used to calculate the charge. For example, some rate structures impose a minimum demand clause. The billing demand is the larger of either the measured demand or the minimum demand.

Clauses used to derive "billing" demand from the measured demand are referred to as "demand determination" clauses. Usually the utility rate sheet will include a "demand determination" section that spells out these clauses. In other cases the clauses are provided as fine print below the demand charge statement

Each utility company defines clauses in different ways, but most fall into one of the following five categories:

- Minimum demand clauses
- Ratchet clauses
- Trailing window clauses
- Demand multiplier clauses
- Power factor multiplier clauses (electric rates only)

Utilities will never refer to the clauses by these names. Instead, these simple descriptive names make explaining the clauses easier. To determine which kind of demand clauses are used in your rate structure, match the clause defined on your utility rate sheet with the following descriptions.

Minimum Demand Clause

Utilities often specify that billing demand may not be less than a certain demand level.

Sample Demand Clause:

The billing demand shall be the larger of:

a. The maximum 30-minute integrated demand measured, or

b. 50 kW

Example 15: In a particular month the measured demand is 35 kW. Using the sample clause above, billing demand would be determined as:

Measured Demand	Minimum Demand	Billing Demand
35 kW	50 kW	50 kW

Ratchet Clause

A ratchet clause introduces a penalty for large swings between monthly demands. The key to recognizing the ratchet clause is that it compares measured demands with a percentage of the highest demand found during a fixed set of months.

Sample Demand Clause:

The billing demand shall be the larger of:

a. The maximum 30-minute integrated demand measured, or

b. 75 percent of the highest demand determined during the billing months of June through August

Example 16: The measured demand for November is 100 kW. The highest measured demand during the months of July through August was 200 kW. Using the ratchet clause above billing demand is determined as follows:

Measured Demand	Ratchet Demand	Billing Demand
100 kW	0.75 * 200 = 150 kW	150 kW

Trailing Window Clause

A "trailing window" clause also introduces a penalty for large swings between monthly demands. The key to recognizing the trailing window clause is that it compares the measured demand in the current month with a percentage of the highest demand found within a series of preceding months. This series of months is referred to as the "trailing window."

Sample Demand Clause:

The billing demand shall be the larger of:

a. The maximum 30-minute integrated demand measured, or

b. 50 percent of the highest demand measured during the preceding 6 months.

Example 17: The measured demand for November is 100 kW. The highest measured demand during the previous 6 months was 250 kW in July. Using the trailing window clause above billing demand is determined as follows:

Measured Demand	Ratchet Demand	Billing Demand
100 kW	0.50 * 250 = 125 kW	125 kW

Power Factor Multiplier Clause

This clause introduces an indirect charge for excessive reactive power use. It is only used in electric rate structures. Power used in alternating current circuits is classified as "working" and "reactive." "Apparent" power is the vector sum of working and reactive power. Working power can be measured by a wattmeter. Reactive power is used to generate the magnetic flux in inductive machinery such as electric motors. It must be measured with separate metering equipment. Rather than measure it directly, utilities sometimes spot check buildings and impose a penalty if reactive power use is excessive. The reference value for the penalty is the "power factor," which is the ratio of working power to apparent power and therefore indirectly indicates the magnitude of the reactive power component. The lower the power factor, the larger the reactive powers use.

Sample Demand Clause:

Customers shall maintain a lagging power factor of 90 percent or higher. For each 1 percent by which the average power factor lags below 90 percent, the demand charge shall be increased by 1 percent.

Example 18: For a certain month the measured peak demand is 200 kW. A spot check indicates the building power factor is 80 percent lagging. Using the demand clause above, the building would be penalized by increasing the demand charge by 1 percent for each 1 percent the power factor is below 90 percent, or a total of 10 percent.

Measured Demand	Power Factor Multiplier Adjustment	Billing Demand
200 kW	200 kW * 1.10 = 220 kW	220 kW

Electric rate structures may have other clauses that are billed, these include items like a fuel adjustment charge, meter charges, and other similar charges. These charges are subject to frequent changes and can be ignored for most LCC studies.

Natural Gas Costs

Natural gas is one of the primary heating fuels in the United States. Natural gas is billed in much the same way that electric usage charges are billed, however gas does not have a demand component to the bill. The units of usage are of course different and natural gas is measured in therms or sometime in cubic feet. A therm is approximately 1000 Btu and is a better measure since the actual heating value of a cubic foot of gas changes over the course of a year and from location to location. The electric utility rate structures above can be used as a guide in determining costs for natural gas.

Natural gas utility bills may have a few other clauses such as a fuel adjustment charges or meter charges. These items can be accounted for in the study if necessary, however since they are often small and vary little between alternatives they could be ignored. In addition, natural gas, like electricity, is sometimes billed in two components a usage charge and a delivery charge.

Other Utility Costs

Other fuels are also used for both heating and cooling. For example, central plants in some locations provide both steam and chilled water. The billing structure is the same as the usage rates for electricity. Additionally, some projects use LP (propane) or fuel oil for heating or indirectly for cooling. Both of these are billed based on the usage, normally measured in gallons.

Water Costs

In some projects water conservation may become an important issue. In many locations, water has become as precious a commodity as energy. Water costs are calculated in a similar manner to other utility costs. When calculating water costs there are often two components to be considered, one for usage and one for disposal. Water is billed with either a flat rate amount per 1,000 gallons used or may use a block structure as described for electricity. As with the other utility costs even through normally billed monthly or quarterly the cost in most studies use one annual cost occurring at the end of the year. The disposal costs may be part of the same bill or a different bill and based on a flat rate or as part of the usage.

Operating and Maintenance Costs

Operating and maintenance costs are the most difficult item to estimate costs for. In many cases it requires a crystal ball as to what will breakdown or how much standard maintenance will cost. They are on going activity in the industry to quantify this number. A few sources for this information including an RS Means Manual for Facility managers.

When considering which costs should be included the operating and the maintenance and repair should be considered. For system operation, consider if the alternative will require different operating personnel or other operating requirements. For example in some places, one system may require an operating engineer while another alternative does not. This can be a major expense since more than one person is required and the costs included both the labor and the workers benefits. When situations like this apply the LCC analysis need to reflect this cost.

The other category of costs is the cost for routine maintenance or repairs. Routine maintenance can be determined by the cost of service contracts that cover both the materials and labor required. It is more difficult when repair costs need to be estimated since it is hard to project when a unit will breakdown. It is always best to carefully consider how much of a difference exists between alternatives to determine if it is significant enough to include in the LCC study. Once again, remember if assumed costs are felt to be out of line the entire study may be discredited. When the costs need to be included, this is a good place to do a sensitivity analysis to evaluate the impact on the final decision.

This completes the first part of our study of HVAC life cycle costs. This is a good time to evaluate your understanding of the material coved Work Session 1 is included at the back of this book and covers this information.

Economic Evaluations

After the cost information has been accumulated, the next step in the process is to calculate the economic measures and make a decision between alternatives. This section discusses economic analysis techniques to measure the benefits of each alternative. The methods used to make a choice between alternatives are also discussed. Each economic calculation method has proper applications and the appropriate ones need to be selected for the analysis being performed. The next step is to decided between the alternatives using the appropriate decision tools depend on the type of decision. In many studies, more than one economic measure may be calculated.

Simple Payback (SPB)

Perhaps the easiest economic analysis technique is the Simple Payback analysis. The "payback" is the time for the benefit to be received by investing a certain amount of capital at the beginning of the life cycle period. An important thing to note about this technique is that it neglects the time value of money and cost escalation is not considered. All costs and savings occurring after the point in time when the payback occurs are neglected. As such, it is much less accurate; however it is very useful for simple, quick answers or as a screening tool to justify the use of a more complex economic analysis method. The SPB period is calculated as follows:

Equation 5

$$\text{Payback Period} = \frac{\text{Net Investment}}{\text{Net Annual Cash Flow}}$$

Of course, if the net annual cash flow is a negative number, the payback period will be negative, indicating the proposal is not economically feasible.

Example 19: A building owner replaces outdated manual thermostats with new programmable thermostats that allow him to setback the temperature during unoccupied time periods and save energy. Assuming the thermostats cost $650 and results in savings of $50/month on his energy bills, calculate the simple payback period of this investment.

$$\text{Payback Period} = \frac{\$650.00}{(\$50/\text{mo.} * 12\ \text{mo./yr})} = 1.08\ \text{yrs.}$$

This results in a payback slightly over one year. The trick to doing these calculations is to always make sure that your units are consistent values before you plug them into the formula. In our case, the 'months' cancel out leaving 'years' as the unit of measurement.

Generally, payback periods of three years or less are the most desirable. The reason for this is covered in the next section.

Return on Investment (ROI)

A similar economic analysis technique is called the Return on Investment (ROI) method. This method is used to compare a design proposal or other capital investment against other benchmark investments such as stocks, bonds or government T-bills. The *minimum attractive rate of return, MARR* is set by the cost analyst or owner and is the minimum acceptable return on the investment. If the particular investment yields a rate of return less than the MARR it would be a better choice to invest in one of the benchmark investments instead of investing in the particular building system or device.

The ROI is actually the reciprocal of the Simple Payback Period, expressed in percentage terms as follows:

Equation 6

$$\text{ROI} = \frac{\text{Net Annual Cash Flow}}{\text{Net Investment}} * 100$$

Example 20: referring to the data from Example 19, calculate the ROI.

$$ROI = \frac{(\$50/mo. * 12mo./yr.)}{\$650.00} * 100 = 92.3\%$$

Not bad considering historically the stock market has yielded around 10 percent annual return and you might get 3-7 percent on a government T-bill, so our scenario appears to be an easy sell to the owner.

It is interesting to note that Simple Payback periods of 3-5 years correspond to ROI rates of 20-33 percent.

Discounted Payback

To overcome the problem of simple payback not addressing the time value of money the discounted payback method was developed. In this method, the cash flows in each year are discounted to the present value and these values subtracted from the investment cost until the value is zero. At the number of years for this to happen is the discounted payback period.

Example 21: A heat recovery system saves $1,200 per year and costs $3,900 to install, the interest rate is 10 percent and the owner will not accept a payback period greater than 4 years should they install the system?

Table 4

Year	Annual Amount	Discounted Amount	Investment – Discounted sum
0	$0	$0	$3,900.00
1	$ 1,2 00.00	$1,090.91	$3,900.00 -$1,090.9 = $ 2,809.09
2	$ 1,200.00	$991.74	$2,809.09 -$991.74 = $ 1,817.35
3	$ 1,200.00	$901.58	$1,817.35 -$ 901.58 = $ 915.77
4	$ 1,200.00	$819.62	$915.77 -$ 819.62 = $ 96.15
5	$ 1,200.00	$745.11	$96.15 -$ 745.11 = $-648.96

Annual Cost Design Alternatives Payback for this example is about 4 years and 2 months. This would not meet the owners' requirements and the decision is to not proceed. Notice if simple payback were used the results would be different as the simple payback is 3 years and 3 months. This indicates the problem with not accounting for the time value of money. Generally, if the payback appears to be longer than 2 to 3 years the discounted method should be used.

Note

Historically payback has been one of the most common methods of determining if a project alternative is economically justified. Simple payback does not account for the time value of money. As a result, simple payback may not yield the best decision. Discounted payback accounts for the time value of money but does not account for the benefit received after the investment cost is recovered.

Simple payback can be used for short recover periods (less than 3 years) and discounted payback can be used for longer recovery periods. To determine the true economic benefit of an alternative other methods should be used.

Annual Cost (AC) Method

This popular economic analysis method is typically used to evaluate multiple design alternatives, each with different design lives or in cases where replacement of a poorly performing piece of equipment or system is being considered. With this method, the assumption is that each alternative will be replaced at the end of its useful life by an identical replacement. This method is sometimes also referred to as the Equivalent Uniform Annual Cost (EUAC) Method.

To use this method the only requirement is that all design alternatives must be mutually exclusive and infinitely renewed up to the duration of the longest-lived alternative. This means that if one alternative has a shorter expected life than the other; it must be replaced with an identical replacement during the life cycle study period.

Example 22: A building owner is trying to decide between using a light-grade HVAC system or a commercial-grade system. Assume the interest rate is 8 percent, as this is assumed to be the benchmark return from alternative investments, also referred to as the MARR. Figure 21 lists the associated costs and useful lives of both alternatives. Using the Annual Cost Method determine which alternative is best.

Alternative	A (Light-grade)	B (Commercial)
Useful life	15 years	20 years
Installed Cost	$12,000	$17,500
Annual Operating Cost (energy + maintenance)	$3,000	$2,500

Figure 19

Annual Cost Design Alternatives

The commercial system costs more to install but operates more efficiently (less expensively) each year and also lasts five years longer than the light-grade system. If the building owner were planning to sell the building before 15 years, he or she would likely go with the least expensive installed alternative (light-grade). However, if the building owner planned to stay in the building permanently, they should consider the fact that the light-grade system will cost slightly more to operate each year and eventually have to be replaced in year 15. To perform an Annual Cost analysis we convert all costs to an annualized basis neglecting inflation or cost escalation. Since the operating and installed costs of both alternatives are already annualized, all we have to do is solve the Uniform Capital Recovery (UCR) formula (Equation A6) using the installed costs and useful lives, then add these values to the known annual costs as follows:

$$EUAC_B = \$12{,}000\left[\frac{0.08\,(1+0.08)^{15}}{(1+0.08)^{15}-1}\right] + \$3{,}000 = \$4{,}402$$

$$EUAC_B = \$17{,}500\left[\frac{0.08\,(1+0.08)^{20}}{(1+0.08)^{20}-1}\right] + \$2{,}500 = \$4{,}282$$

Therefore, alternative B (commercial), with the lower annual cost, is the best alternative.

Life Cycle Cost (LCC) Method or Present Value Analysis

As described before the LCC Method is a comprehensive method that accounts for all costs incurred and benefits received. This is the most useful and most widely applicable economic analysis method. It can be used for all types of analyses except for rank-ordering or prioritizing independent projects. The SIR or IRR methods are required for those types of projects, which are covered in later sections.

The LCC includes the costs to acquire, design, construct, operate, maintain, and subsequently dispose of the facility or system. As was shown before the generalized life cycle cost (LCC) equation is written as follows:

Equation 5

$$LCC = I + R + E + W + OM\&R - RV$$

Where:

I	=	capital investment costs
R	=	capital replacement costs
E	=	energy costs
W	=	water costs
OM&R	=	operating, maintenance & repair costs
RV	=	residual value (salvage less disposal costs)

All costs are in present value (PV) terms. Capital investment costs are assumed to occur at the beginning of the study period, therefore they are already in PV terms. Other costs may occur at different times over the economic life and are all discounted to their respective PV using appropriate discount and cost escalation factors. Finally, the PV of each component cost is summed to arrive at the total (LCC). The alternative with the lowest LCC is the most favorable alternative.

Example 23: Two different HVAC systems are being considered for a new building; a constant-volume (CV) system and a variable-volume (VAV) system. The VAV system costs 20 percent more to install but saves 25 percent on annual utility costs. In addition, the VAV system fan uses a variable frequency drive (VFD) that extends the life of the fan motor to fifteen years while the supply fan motor in the CV system must be replaced at year seven. Assume the discount rate is 7 percent and the escalation rate for annual operating costs is 3 percent. Neglect the cost for water and neglect the cost escalation for the fan motor. Assume a zero salvage value for both alternatives.

Figure 20 lists all required data for both alternatives. Using the LCC method, determine the most favorable alternative.

Alternative	CV	VAV
Useful life	15 years	15 years
Installed Cost	$35,000	$42,000
Annual Operating Cost (energy)	$3,500	$2,625
Annual Maintenance Cost	$1,500	$1,750
Capital Replacement Cost (replace fan motor in year 7)	$2,000	N/A
Salvage Value	N/A	N/A

Figure 20

LCC Analysis Alternatives

To perform a LCC analysis we must convert all costs to their PV. The installed costs are already in PV terms, however the annual operating and maintenance costs and the capital

replacement cost for the base case in year 7 must be discounted to PV terms using appropriate equations.

Because there is an escalation rate for the annual operating and maintenance costs, we will use Equation A8 to discount them. For the capital replacement cost incurred in year 7, we simply use the PV equation (Equation A2).

Therefore, the VAV system is the preferred alternative since the LCC is lower. In addition, the VAV system is likely result in enhanced occupant comfort, however this advantage is difficult to quantify. When conducting any economic analysis you should always consider all factors, including subjective ones prior to making a final decision.

With the LCC method there is no base case required, although you must have at least two alternatives for comparison, one of which could simply be to *do nothing*. Also, make sure that you use consistent economic assumptions (economic lives, interest and discount rates) for all alternatives.

	CV	VAV
Initial Investment Cost [already in PV]	$35,000	$42,000
Capital Repl. Cost PV (replace fan in year 7) [Eq. A2, *i* = 7%, *N* = 7]	$ 1,245	$0
Annual Energy Cost PV [Eq. A7, *i* = 7%, *e* = 3%, *N* = 15]	$39,233	$29,425
Annual OM&R Cost PV [Eq. A7, *i* = 7%, *e* = 3%, *N* = 15]	$16,814	$19,617
Total (PV) LCC	**$92,292**	**$91,042**

Figure 21

Discounted Costs

Internal Rate of Return Method

The IRR method is a *relative* cost analysis method in that all project alternatives are evaluated against a *base case*, which is generally the alternative with the lowest installed or first cost and the highest operational costs. The IRR method is usually used to compare two or more independent investment alternatives. If the calculated IRR is greater than MARR, the alternative is economically justified. The alternative with the greatest IRR is the most favorable investment.

The actual return on any particular investment is calculated by computing the equivalent discount rate that will make the present value (PV) of all cash flows (inflows & outflows) from the investment equal to the investment cost. This equivalent discount rate is called the *Internal Rate of Return* (IRR). The IRR is often calculated using a trial-and-error approach by setting the PV of all future cash flows equal to the investment amount, as the following equation illustrates:

Equation 6

$$PV = \frac{C_1}{(1+i)^1} + \frac{C_2}{(1+i)^2} + \frac{C_3}{(1+i)^3} + \ldots\ldots + \frac{C_N}{(1+i)^N}$$

Where:

C_N = cash flow amount in year N

N = number of years

PV = investment amount

i = internal rate of return

Example 24: Assume a building owner is considering adding an outdoor air economizer to an existing rooftop HVAC unit to save energy. From a previously conducted energy analysis estimate, the following cost data has been collected:

Assume that the total cost to purchase and install the economizer is $1,200, and that the building owner can invest money at the bank at an interest rate of 7.5 percent, compounded annually. This interest rate then becomes the owner's MARR, which is the benchmark rate of return from alternative investments. So, the question becomes, should the owner invest $1,200 at the bank or purchase the economizer?

Since we now know all of the variables required, except for *i*, we can perform a trial-and-error calculation assuming a value of *i* that will make the cost of the economizer and the present value of all of the annual energy cost savings equal.

Year	Annual Energy Cost w/o Economizer	Annual Energy Cost with Economizer	Annual Energy Savings
1	$ 926	$ 648	$ 278
2	$ 973	$ 681	$ 292
3	$1021	$ 714	$ 307
4	$1072	$ 750	$ 322
5	$1125	$ 787	$ 338
Total	$5117	$3580	$1537

Figure 22

Annual Energy Cost Data

Let's first assume $i = 10$ percent:

$$PV = \$1200 = \frac{\$278}{(1+.10)^1} + \frac{\$292}{(1+.10)^2} + \frac{\$307}{(1+.10)^3} + \frac{\$322}{(1+.10)^4} + \frac{\$338}{(1+.10)^5}$$

$$= 252.73 + 241.32 + 230.65 + 219.93 + 209.87 = \$1154.50$$

Because the calculated value of *PV* is not equal to $1,200, we must assume a new value for ***i***.

Let's assume i = 8 percent:

$$PV = \$1200 = \frac{\$278}{(1+.08)^1} + \frac{\$292}{(1+.08)^2} + \frac{\$307}{(1+.08)^3} + \frac{\$322}{(1+.08)^4} + \frac{\$338}{(1+.08)^5}$$

$$= 257.41 + 250.34 + 243.71 + 236.68 + 230.04 = \$1218.18$$

Now the calculated value of *PV* is close to $1,200, but not exactly equal. We now know that the actual value of *i*, which makes the annual savings equal to the investment amount, is somewhere between 8 percent and 10 percent. Using interpolation, the correct value of *i* may be determined as follows:

8% = $1,218.18

I = $1,200.00

i = **8.6%**

10% = 1,154.50

Once the actual *IRR* is determined, it should be compared to the minimum attractive rate of return (*MARR*). Once again, the MARR is the lowest acceptable return on investment as determined by the investor. This value could be equal to the rate of return for government treasury bills or common stocks for instance. *If the IRR > MARR, the proposal is feasible.* In this case since the MARR is 7.5 percent, the economizer is a good investment with an IRR of 8.6 percent.

Net Savings (NS) Method

The Net Savings method is a supplementary economic cost analysis method closely related to the previously discussed LCC method. The NS method is sometimes also referred to as the *Net Benefits* method. Given identical inputs and assumptions, the NS method will yield results consistent with the LCC method; that is the alternative with the lowest LCC will be identified.

Similar to the IRR method, the NS method is a relative cost analysis method in that all project alternatives are evaluated against a base case. The base case is generally established as the lowest first-cost alternative. With the NS method, the discount rate used must be equal to the analyst's MARR.

The objective of the NS method is to demonstrate that the incremental cost of the alternative case(s) over the base case is justified based on operational cost savings alone. As long as the NS is greater than zero for the alternative, as compared to the base case, then the alternative is a better selection.

It should be noted that the base case might be to *do nothing*. For example, a facility may be considering replacing older, less-efficient electric motors with new high-efficient motors. The existing motors may be still functioning, therefore one alternative may be to do nothing and leave the existing motors in place until they fail, then replace them. Another alternative may be to replace them all immediately and a third alternative may be to replace them one-at-a-time, annually at a future date for instance or as budgets allow.

When compared to the LCC method, one disadvantage of the NS method is you must establish a base case for comparison. In addition, with the NS method, all project alternatives must have identical useful lives and identical discount rates.

Net Savings is calculated as follows:

Equation 7

$$NS = LCC_{\text{Base Case}} - LCC_{\text{Alternative}}$$

A positive value of NS means the alternative is justified, that is the LCC of the alternative is less than that of the base case. The NS is simply the estimated long-term profitability of the alternative considered. For our previous LCC method problem, Example 23, the NS may be calculated as follows:

$$NS = \$92{,}292 - 91{,}042 = \$1{,}250$$

The result is a positive number indicating that the incremental first cost of Alternative A (VAV system) is cost-justified based on the operational savings over the base case. Another way to interpret the NS>0 is the IRR of Alternative A is greater than the MARR.

Savings-to-Investment Ratio (SIR) Method

This is another supplemental cost analysis method often used by public sector entities such as municipalities and government agencies. Similar to the previously discussed NS and IRR methods, the SIR is a relative performance measure and is only relevant with respect to a base case.

Several types of cost analyses can be evaluated using the SIR method. These include a simple accept/reject decision, a rank ordering of competing, independent projects, and analyzing a group of mutually exclusive alternatives. We will explore each of these three decision types in the next sections using the SIR method.

Accept/Reject Decision

With this type of analysis, the goal is to determine the cost-effectiveness of a single project alternative. Should we implement this project? The analysis will result in either a "go" or "no go" decision depending on the results obtained. If the SIR is greater than 1.0, then the alternative is accepted. If the SIR is less than 1.0, the alternative is rejected. For this type of analysis the base case is to simply *do nothing* and the SIR is defined as follows:

Equation 8

$$SIR = \frac{\text{NPV Savings from Alternative}}{\text{NPV Cost of Alternative}}$$

The savings (numerator) consists of all energy, maintenance and any other savings realized by implementing the alternative. The cost (denominator) includes purchase, installation, and any benefits received (e.g., utility rebate) by implementation of the design alternative.

Example 25: It has been determined from a computerized energy simulation and cost calculation that adding storm windows to a building results in a life cycle cost (LCC) savings of $88,500 over 25 years. A MARR of 8 percent was used to calculate the LCC. The installed cost to replace the storm windows is $65,000. Calculate the SIR and determine if the storm windows should be installed.

In this example all costs are already in PV terms, therefore, no additional discounting is required. The SIR = $88,500 / 65,000 = 1.36, which is >1.0, therefore, the storm windows should be installed resulting in a net savings (NS) of $23,500 (88,500 – 65,000). Another way to interpret the result of this analysis is the IRR of the alternative is greater than 8 percent (MARR) because there is a positive NS amount.

The next type of analysis that can be performed using the SIR method is rank ordering or prioritizing competing, independent projects.

Rank-Ordering Competing, Independent Project Alternatives

With this type of analysis, the budget generally is established beforehand and the analyst's job is to prioritize a group of potential project alternatives and decide which ones should be implemented until the budget is depleted.

The following procedure should be used to evaluate competing, independent project alternatives:

SIR Analysis Procedure for Analyzing Competing, Independent Project Alternatives

1. Compute Total Investment and Operating Cost Cash Flows for each alternative and then sum all annual costs. Investment costs include any down payments, loan principal, or interest, plus any non-capital investment costs less any investment benefits. Operating costs include energy, maintenance, insurance, and property taxes. Income taxes are not considered.
2. Convert all Investment and Operating Costs Cash Flows to their Present Values (PV) using the minimum attractive rate of return (MARR) as the discount rate.
3. List the alternatives in a table including all investment and operating costs and all operational savings.
4. Calculate the resulting SIR for each alternative by dividing the savings by the investment (Equation 9). Each alternative with a resulting SIR>1.0 is deemed acceptable. Alternatives with SIR<1.0 are eliminated from consideration.
5. Rank-order all alternatives in descending order from highest to lowest SIR. Projects should be funded in that same order.
6. If budget limitations exist fund projects in order until budget is depleted. If project costs are "clustered" such that implementation of projects in descending order of SIR is not possible, you may have to use a trial-and-error approach analyzing several combinations of alternatives that utilize the largest amount of the available budget. The combination of alternatives that maximizes the aggregate net savings is the preferred combination. For instance, it may make more sense to implement one alternative that has a lower SIR if that alternative uses more of the available budget (see Example 26).
7. If budget limitations do not exist, fund projects in descending order from highest to lowest SIR.

Let's look at an example analyzing competing, independent alternatives.

Example 26: Given the following four competing, independent project alternatives, calculate the SIR for each alternative and rank-order the alternatives. Assume the available budget amount is $50,000. Decide which alternatives should be implemented and what order they should be funded.

From Figure 23 you can see that all four alternatives have an SIR>1.0, indicating that all are cost-effective; that is in all cases the savings amount exceeds the investment amount and the corresponding IRR>MARR. In addition, Alternate D has the highest SIR at 1.49 receiving a ranking of "1" followed by Alternative B, then A, then C.

Alt.	Savings	Investment	SIR	SIR Rank
A	$12,225	$10,000	1.22	3
B	$18,880	$13,500	1.40	2
C	$17,500	$15,800	1.11	4
D	$26,000	$17,500	1.49	1

Figure 23

SIR of Competing, Independent Alternatives

The problem stated that the available budget was $50,000. Can we implement all four alternatives? If we sum the investment costs for all four alternatives we get $56,800. Unfortunately, this exceeds the available budget; therefore, we must eliminate one of the alternatives from consideration. Which one? Alternative C has the lowest SIR, if we eliminate Alternative C the cost of the other three alternatives (A+B+D) sum to $41,000. This leaves $9,000 left unspent. Now things get more complicated. If you have any experience with managing budgets you know that if you don't spend your entire budget this year, next year it gets cut.

Now let's suppose it's your company and your goal is to minimize expenditures, therefore you may be content with spending only $41,000 of the available budget, however, is that really the best decision from a pure financial standpoint? Let's look at it another way. Alternative A costs $10,000 and Alternative C costs $15,800. What if we eliminated Alternative A instead of Alternative C and instead we implemented Alternative C? Even though Alternative C has a lower SIR (1.11) than Alternative A (1.22), implementing Alternative C consumes more of our available budget, therefore maximizing our overall rate of return.

Since all four alternatives have been deemed cost-effective, we should attempt to implement as many of the alternatives as possible. After all, the more we spend the more we save. Another way to look at this is all alternatives have an IRR > MARR provided the MARR is used as the discount rate to convert all costs to their respective PV terms.

If we implement Alternatives D, B, and C (in that order) we will consume a total of $46,800, leaving only $3,200 unspent. This results in a higher aggregate net savings (NS) for the entire project.

The ultimate solution, however, is to determine if Project C can be broken into parts and partially or individually funded, each part having the same SIR. If not divisible into parts, Project C should be skipped and Project A fully funded, leaving $3,200 unspent. The reason we don't simply skip Project C, without determining if it can be divided into parts, is the aggregate net savings is maximized by funding and implementing as many of the project alternatives as possible, since all have SIR>1.0 and MARR>IRR.

Of course, if unlimited funds were available, you would implement all four alternatives in the order shown in Figure 23. Another tactic might be to appeal to the management to increase the budget to $56,800 so all alternatives may be implemented as this maximizes the overall rate of return. You can begin to see that cost analyses are not always straightforward or in black and white.

Mutually Exclusive Alternatives

The final type of analysis we will discuss, as part of the SIR method, is evaluating a group of mutually exclusive project alternatives. To analyze a group of mutually exclusive project alternatives using the SIR method you must use an incremental analysis technique. The method is incremental because it compares the additional (incremental) investment between competing alternatives to the incremental savings produced by each alternative. When using the SIR method, all design alternatives must have identical useful lives and discount rates.

For this type of analysis, the savings-to-investment ratio (SIR) is equal to the ratio of incremental present value (PV) operational cost savings divided by the PV of the incremental investment cost for the alternative. Stated another way, the SIR is equal to the amount of savings generated by each incremental dollar invested. For instance, an incremental SIR of 2.5 indicates $2.50 in additional savings for every additional $1.00 invested. With an SIR analysis we are looking for alternatives that yield an SIR>1.0, also indicating a positive Net Savings (NS) and an IRR>MARR.

As stated previously, the SIR method discounts all annual costs and annual savings to their net present values (NPV), and is calculated as follows:

Equation 9

$$SIR = \frac{NPV\ \Delta\ Operating\ Costs}{NPV\ \Delta\ Investment\ Costs}$$

Where:

Δ Operating Costs = Operating Cost Difference between Alternatives

Δ Investment Costs = Investment Cost Difference between Alternatives

It is very important to understand that the SIR method should not be used to evaluate multiple, mutually exclusive project alternatives unless you use an incremental analysis procedure. The reason for this is an SIR number, by itself, is meaningless unless you are talking about a simple accept/reject decision or a rank ordering of competing, independent alternatives.

If you have several mutually exclusive alternatives and you simply calculate the SIR of each alternative by dividing the savings by the cost (investment), the resulting SIR is meaningless. For analyzing mutually exclusive alternatives, the SIR is only meaningful and reliable when it is calculated by dividing the alternative's incremental savings by the incremental investment cost.

The whole idea of an incremental analysis of mutually exclusive alternatives is to justify the additional investment amount for each alternative compared to the additional savings realized by the alternative. In order to do this you must arrange your alternatives in ascending order from lowest initial cost to highest initial cost. That way you can easily compute the incremental values. The following procedure should be used to evaluate mutually exclusive project alternatives:

Mutually Exclusive SIR Analysis Procedure

1. Compute Total Investment and Operating Cost Cash Flows for each alternative and then sum all annual costs. Investment costs include any down payments, loan principal or interest, plus any non-capital investment costs less any investment benefits. Operating costs include energy, maintenance, insurance, and property taxes. Income taxes are not considered.
2. Convert all Investment and Operating Costs Cash Flows to their Present Values (PV) using the minimum attractive rate of return (MARR) as the discount rate.
3. Organize alternatives in order from lowest first cost to highest first cost. The alternative with the lowest first cost is considered the base case. Calculate the incremental savings and incremental investment amounts between the base case and the first alternative.
4. Calculate the resulting incremental SIR values. If the incremental SIR of the first alternative is >1.0 the first alternative wins over the base case. If the SIR<1.0 the first alternative is eliminated from further consideration and you move on to the next alternative in order. Each time comparing the incremental cost and investment differences between each alternative and then computing the resulting incremental SIR. Additional investment amounts are cost-justified as long as the incremental savings exceeds the incremental investment or until the SIR for the remaining alternatives is <1.0. The optimum selection is obtained when the incremental investment amount equals the incremental savings (SIR=1.0) or when the SIR is as low as possible, but still >1.0.

Let's look at an example of analyzing mutually exclusive project alternatives using an incremental SIR approach.

Example 27: The following table contains data for four mutually exclusive project alternatives including the incremental savings, incremental cost, and incremental SIR of each alternative.

Alt.	Svgs.	Δ Svgs.	Inv.	Δ Inv.	Incr. SIR
1 (base)	12,225	0	10,000	0	0
2	18,880	6,655	13,500	3,500	1.90
3	17,500	1,380	15,800	2,300	0.60
4	26,000	7,120	17,500	4,000	1.78

Figure 24

SIR of mutually exclusive alternatives

According to the data, Alternative #2 costs $3,500 more than the base case but it generated $6,655 of incremental savings over the base case, yielding an incremental SIR of 1.90, therefore it is preferred over the base case and the base case is eliminated from further consideration.

Next, we compare Alternative #3 to Alternative #2 by calculating the incremental cost and savings amounts between alternatives. Alternative #3 requires an additional $2,300 investment, however this yields an incremental savings of only $1,380 and an SIR = 0.6. In other words the incremental savings for Alternative #3 is less than the incremental cost (SIR<1.0); therefore, this alternative is eliminated from further consideration.

Since Alternatives #1 and #3 have been eliminated, we now can move on and compare Alternative #4 to Alternative #2. Again, we compute the incremental costs and incremental savings amounts between alternatives. Alternative #4 costs $4,000 more than Alternative #2 but yields $7,120 in additional savings, resulting in an incremental SIR = 1.78.

Which alternative is preferred; Alternative #2 with the highest SIR? *Do not be misled into thinking that the alternative with the highest SIR is always the best choice.* The only time that you should select the alternative with the highest SIR is when analyzing a single design alternative for an accept/reject type decision or for an analysis involving independent alternatives. That is one reason the SIR method is sometimes confusing.

When analyzing these types of situations, such as selecting the optimum choice from a group of mutually exclusive design alternatives, it always pays to continue to expand the incremental investment as long as the incremental savings exceeds the incremental cost; that is as long as the alternative has an SIR>1.0. Once the SIR=1.0 you have optimized the selection. Actually, the alternative that maximizes the net savings (NS) is the alternative with the SIR = 1.0, provided you used an incremental analysis technique to compare alternatives.

Therefore, from the data in Figure 24 we determine that the preferred alternative is Alternative #4 because it provides the largest total net savings. For an investment of $17,500, you save $26,000 for $8,500 net savings – compared to Alternative #2 which costs $13,500 and saves $18,800 for only a net savings gain of $5,300. To reiterate, when performing an analysis of mutually exclusive alternatives, either you must use an incremental SIR method or the LCC or NS methods.

This was a simple example involving only present value amounts. In most cost analyses, we must discount all costs over the useful life to PV terms and include an escalation rate for the costs. SIR calculations are best-performed using calculation programs because the data becomes complicated and there are plenty of opportunities for making erroneous calculations.

Let's now look at another example demonstrating the differences between the incremental SIR, the LCC and the NS methods.

Example 28: An engineer is trying to determine the optimal insulation type to be used for a roof of a new building. Various thermal insulation types are considered. Their associated installed and energy cost present values (PV) are summarized in Figure 25. It should be noted that this is a hypothetical example only. The optimum level of insulation for a particular building depends on many factors (local weather, labor costs, energy costs, etc.) and should be evaluated on an individualized basis.

Design Alternative	Insulation R-value	Initial Cost $ (PV)	Energy Cost (life) $ (PV)
Base Case	R-0	$0	$238,028
A	R-11	$3,000	$201,772
B	R-19	$4,700	$199,813
C	R-30	$6,800	$198,712
D	R-38	$9,500	$198,311

Figure 25

Cost Data

Calculate the LCC, SIR, and NS for each alternative. Compare and contrast the results between each method. Finally, determine which design alternative is most cost-effective using all three cost estimating methods.

For any analysis of this type where you are attempting to optimize the level of efficiency for a building system, you should use the incremental SIR, life cycle cost (LCC), or NS analysis method. The option with the lowest LCC or greatest NS would be the best option. The LCC method is usually the most reliable method for conducting mutually exclusive project alternatives.

The first task is to decide if the analysis involves mutual exclusive, independent, or interdependent alternatives. Since this is a task to optimize the quantity of insulation and only one level of insulation can be selected, this is a mutually exclusive analysis.

It is important to note that the alternative with the lowest LCC is not always the alternative with the highest SIR. Therefore, the alternative with the highest SIR is not necessarily or usually the most economical selection. For this example, because these alternatives are mutually exclusive, the SIR method should not be used unless an incremental analysis between alternatives is considered.

Since the base case is to use no insulation (R-0), R-11 insulation will have a higher SIR than R-19. This is because when compared to no insulation, the R-11 savings will be much greater than the incremental savings by increasing the insulation from R-11 to R-19. Similarly, by increasing the insulation from R-19 to R-30 to R-38, the SIR will decrease further because the cost-effectiveness of insulation diminishes as the R-value increases. In other words, at some point it no longer pays to add additional insulation. The goal is to find the optimum level of insulation.

Alt.	Total LCC $ (PV)	Δ Init. Cost $ (PV)	Δ Op cost Svgs. $ (PV)	SIR	NS
Base	238,028	0	0	0	0
A	204,772	3,000	36,256	12.1	33,256
B	204,513	1,700	1,959	1.2	33,515
C	205,512	2,100	1,101	0.52	32,516
D	207,811	2,700	401	0.15	30,217

Figure 26

Economic Calculation Results

The next step is to compute the sum of all cash flows, then convert into PV terms. Since all values are

already in present value (PV) terms, discounting is not required in this example. Next we compute the total LCC of each alternative. The LCC is the sum of the initial costs for the insulation plus the PV of all energy costs over the life of the study. Now we calculate the incremental cost differences between each alternative and the base case. This is the difference between the initial costs and operating costs of each alternative. Next, we calculate the net savings (NS) for each alternative compared to the base case, which is equal to the Total LCC of the base case less the Total LCC of each alternative. The SIR is the ratio of the incremental savings of each alternative divided by the incremental cost. Results are shown in Figure 26.

From the results, we can see that Alternative B has the lowest LCC and the greatest NS. The SIR of Alternate A is 12.1. From the results of the SIR analysis alone we might conclude that Alternate A is the best selection, however this shows the inconsistency of results that sometimes occurs when using the SIR method for evaluating mutually exclusive alternatives. Because the R-11 insulation demonstrated the largest incremental benefit verses no insulation, this alternative appears to offer the best choice, however for a LCC analysis over 25 years, the R-19 insulation (Alternative B) resulted in the lowest life cycle cost. The key point to understand when performing an incremental SIR analysis is the highest SIR is not always, or even frequently, the best choice. As you can see from the data in Figure 26, for Alternatives C and D, the incremental SIR is <1.0 indicating that the incremental savings of these alternatives is less than the incremental cost, therefore, Alternatives C and D should be eliminated from further consideration.

In reality we probably would not consider a study with no insulation, therefore had the base case been to use R-11 rather than R-0 (no insulation) the SIR, LCC and NS methods would have yielded consistent results, all indicating R-19 as the best choice.

In summary, for mutually exclusive alternatives you should use the LCC or NS methods. Alternatively, you can use an incremental SIR analysis; however, the LCC or NS methods will always yield consistent results whereas the SIR method does not always, as demonstrated by the previous example.

We will now look at the economic decision-making process and criteria that must be considered along with suggested economic analysis methods for various types of design decisions.

Economic Evaluation Criteria

Given all of the various methods available for performing a life cycle cost (LCC) analysis you might be understandably confused at this point as to which method to use. As discussed, the first step in the decision-making process of a cost analysis is to clearly define the problem and the desired objective. Once it is determined that an economic analysis is necessary, the cost analyst must decide the level of sophistication and complexity required to satisfy the desired objective. Next, the analyst must identify and list all potential alternatives for accomplishing the desired objective, considering all constraints.

The identification of constraints is very important because constraints limit the economic evaluation techniques available. Economic evaluation decisions may be broadly segmented into the following five categories:

1. Accept or reject a single system or project alternative
2. Optimize the design or efficiency level of a building or building system
3. Determine the optimum building system type given multiple alternatives
4. Determine the optimum combination of interdependent building systems
5. Rank-order (prioritize) independent, competing projects with or without funding constraints

Accept or Reject a Single System or Project Alternative

For example, is it cost-effective to add an energy management control system to an existing building?

This type of analysis is performed for a single alternative. This type of analysis is either "go" or "no go." The base case is generally to do nothing, and there are no other competing alternatives involved. The base case generally has a higher operational cost than the alternative. In some instances the base case may include a capital expenditure to extend the useful life of the existing system to the end of the life cycle study period. For instance, a major compressor overhaul or cost of replacing the heat exchanger tubes on a chiller may be analyzed against replacing the entire chiller.

For an accept/reject analysis, any of the following cost analysis methods will consistently and reliably indicate the most cost-effective alternative: LCC, NS, SIR, and IRR.

Optimize the Design or Efficiency Level of a Building or System

For example what cooling system efficiency level (EER) should be selected given various alternatives?

This type of analysis differs from the accept/reject analysis in that the objective here is to select the most cost-effective system from a list of mutually exclusive alternatives, not to simply justify each alternative as acceptable.

The optimum efficiency level for a building or building system will be the one that minimizes the life cycle costs (LCC) while maximizing the net savings (NS). For this type of decision, it is recommended that you use either the LCC or the NS method. You should not use the SIR or IRR methods unless you use an incremental analysis procedure. You should also not use the Simple Payback (SPB) method, as it will likely yield inconclusive results. However, you may use the SPB method as a quick screening tool for analyzing a single project alternative.

The reason the LCC and NS methods are preferred for mutually exclusive project alternatives over the SIR, incremental IRR and SPB methods is the alternative with the highest SIR or IRR and the shortest payback period will not necessarily be the most cost-effective solution given various alternatives. This is because the additional energy savings values tend to diminish with each incremental increase in efficiency levels. If project costs are "lumpy," that is they are clustered together and large differences exist between the base case and any of the alternatives, the SIR and IRR methods may yield inconclusive results.

Determine the Optimum Building System Type Given Multiple, Mutually Exclusive Alternatives

For example, which type of heating fuel source should be used for this building: electric, natural gas, propane, or heat pump?

With this type of analysis, the primary concern is not normally the amount of energy consumed; rather it is to maximize the overall cost-effectiveness (minimize LCC) of the entire installed system, including energy, OM&R, and installation costs. In addition, with this type of analysis it is assumed that the optimum energy efficiency level for each alternative system has already been determined. For instance, prior to determining the optimum heating system type, a gas heating system has been previously optimized by selecting the system with the highest annual fuel utilization efficiency (AFUE) and the lowest LCC.

For this type of decision, you must use identical useful lives and a common discount rate (MARR) for all alternatives. For this type of decision, the recommended analysis method is either the LCC or NS methods. It is recommended that you not use the SIR or IRR methods, unless you use an incremental approach, since they may yield inconsistent results.

Determine the Optimum Combination of Interdependent Building Systems

For example, what is the best combination of HVAC system efficiency, lighting system efficiency, or building thermal envelope? Building systems are interdependent in that the performance of one system affects the efficiency or energy consumption of the other. For instance, high-efficiency lighting or high-performance glass reduces the cooling load on the HVAC system, hence affecting the HVAC system efficiency. Increasing the thermal efficiency of the building envelope reduces the buildings cooling load and diminishes the cost savings of utilizing a higher-efficient HVAC system. Likewise, increasing the HVAC system efficiency diminishes the effects of improving the building envelope efficiency.

For a new building, the combination of possibilities is nearly endless; however, for a renovation the list of available building system choices is usually limited. For instance, if the walls are already constructed you probably would not consider tearing out walls to add additional insulation.

With this type of decision, a detailed building energy simulation should be performed first to determine the annual energy consumption values for each alternative. A program, such as Carrier's HAP – Hourly Analysis Program, can be used to calculate annual energy costs. These types of programs do not usually automatically perform every combination of variables to determine the optimum combination. Instead, the analyst generally must create a matrix containing combinations of each variable to analyze prior to performing the annual energy cost calculations.

For this type of decision a typical question might be: "Should I purchase a higher-efficient HVAC system or spend more money to improve the thermal performance of the building envelope?" Energy standards such as ASHRAE 90.1 specifically address these types of decisions. The goal is to achieve a specific minimum acceptable level of total building energy consumption. Buildings that meet or exceed a particular benchmark are deemed acceptable. Often there are multiple ways of achieving the same end result. The goal is to reduce the overall building life cycle costs (LCC); therefore, there are usually multiple combinations of alternatives available to achieve this goal. Let's look at an example.

Example 29: A designer is trying to decide between three types of building envelopes, and three levels of HVAC system efficiencies, each with incrementally higher efficiency levels. Using a detailed, whole building energy simulation the annual operating costs has been determined. This information and relevant installation and OM&R costs have been compiled. Life cycle costs (LCC) have been calculated by discounting all costs to their PV using the MARR. A matrix of the LCC results has been developed as follows:

Envelope	HVAC System H1	HVAC System H2	HVAC System H3
E1	241,492	216,758	210,423
E2	226,812	207,431	202,550
E3	218,754	**190,880**	196,425

Figure 27

LCC of Combination of Envelope and HVAC System, ($)

The combination of envelope and HVAC system that yields the lowest LCC is the preferred combination. From Figure 27, this is the combination E3/H2. In this example the higher efficiency of HVAC system H3 could not be cost-justified when combined with envelope E3.

The net savings (NS) procedure can also be used to give identical results, however with the NS method a base case must be selected. A base case is not required with the LCC method.

The SIR, IRR, and SPB methods are not recommended for this type of analysis, as they may not yield the optimum results under all circumstances.

Prioritize Independent Competing Projects with or without Funding Constraints

For a given fixed amount of available capital, which combination of energy conservation measures is most cost-effective?

All of the other four decision types involve mutually exclusive alternatives, meaning only one alternative can be selected. This type of decision is used to rank-order independent, competing projects that have each already been determined to be cost-effective alternatives. Each alternative is independent since the selection or implementation of one alternative does not affect the others. The task is to determine the optimum combination of alternatives that maximizes the aggregate net savings (NS).

Since all alternatives have previously been identified as cost-effective, the ultimate decision would be to implement all alternatives, however in reality budgets usually limit the amount of available funds.

The recommended cost method for this type of decision is either the IRR or SIR method. Each alternative is rank-ordered using the IRR or SIR method and are funded in descending order from highest to lowest SIR until all available funds are depleted. Should additional funding be made available later, projects remaining are then funded using similar criteria.

It is recommended that you do not use the LCC, NS, or SPB methods for ranking independent projects, as those methods are only applicable for mutually exclusive projects.

An advantage of using the SIR method is that alternatives with varying service lives may be analyzed, in contrast to mutually exclusive projects where all alternatives must have the same service lives. For this decision type, using the SIR method, you do not replace systems at the end of their service lives as with mutually exclusive projects. For instance, suppose a chilled water HVAC system, with a service life of 23 years, is being compared to a packaged rooftop unit HVAC system with a service life of 15 years. You do not have to consider a replacement of the rooftop unit system at the end of year 15. The next example illustrates this type of decision.

Example 30: Five projects are listed in Figure 28. Projects are listed in descending order of highest to lowest SIR. Projects will be funded in order shown, based on available funds.

To illustrate, let's assume that the capital budget available is $5,000. From the results, you can see that the first three projects (C, B & A) may be funded, with $100 remaining unspent.

Alt	Initial Cost	Total Svgs	SIR	Net Svgs. NS	Cumulative Invst.	Cumulative NS
C	1,200	6,800	5.7	5,600	1,200	5,600
B	1,300	5,850	4.5	4,550	2,500	10,150
A	2,400	9,840	4.1	7,440	4,900	17,590
E	4,500	14,400	3.2	9,900	9,400	27,490
D	3,500	4,875	1.4	1,375	12,900	28,865

Figure 28

SIR Ranking of Independent, Competing Projects with Cost Constraints, ($)

Suppose however that the budget is $8,500. This means that once again projects C, B & A may be funded. This time there is $3,600 remaining unspent. Project E requires $9,400 in total funds.

Now what do you do if you do not want to have money unspent? We have $3,600 remaining to allocate. The preferred solution is to determine if Project E can be broken into parts and funded individually, each having the same SIR. If not divisible into parts, Project E should be skipped and Project D fully funded, leaving $100 unspent. The reason we do not simply skip Project E, without determining if it can be divided into parts, is the SIR is higher for Project E than for Project D.

For independent, competing projects, the SIR is not computed based on an incremental technique, as we used on the mutually exclusive analysis. Instead, you compute the SIR by simply dividing the total savings amount of the alternative by its initial cost

This concludes the discussion of economic analysis methods. Table 4 summarizes all of the economic analysis methods and provides guidelines for usage.

Table 4
Economic Evaluation Methods and Recommended Procedures

Recommended Economic Analysis	Decision Type					Limitations of Method
	Accept/ Reject Single Alternative	Optimize Design or Efficiency Level	Select Optimum System Type	Determine Optimum Combination of Interdependent Systems	Rank Order Independent Projects with or without Budget Constraints	
SPB Simple Payback	Yes[a]	No	No	No	No	Ignores time value of money, costs, and savings. May not always reveal cost justifications.
LCC Life Cycle Cost	Yes (minimize)	Yes (minimize)	Yes (minimize)	Yes (minimize combined LCC)	No	Single value of LCC gives no indication of economic merit, 2 or more values required. All projects must have same economic lives & discount rates.
NS Net Savings	Yes (if > 0)	Yes (maximize)	Yes (maximize)	Yes (maximize combined NS)	No	Yields same results as LCC method, however a baseline case is required. All projects must have identical economic lives & discount rates.
SIR Savings-to-Investment Ratio	Yes (if > 1.0)	Yes, only if incremental method is used	Yes, only if incremental method is used	No	Yes[b] (descending order)	Requires the use of a baseline case. All projects must have same economic lives & discount rates. Not applicable for choosing among mutually-exclusive projects unless incremental method used.
IRR Internal Rate of Return	Yes, (if IRR>MARR or discount rate	Yes, only if incremental method is used	Yes, only if incremental method is used	No	Yes[b] (descending order)	Requires the use of a baseline case. All projects must have same economic lives & discount rates. Not applicable for choosing among mutually-exclusive projects unless incremental method used.

a) The SPB method is mostly useful as a screening tool or in cases where it is obvious that the proposal is economically justified

b) Projects should be funded in descending order of SIR or IRR until all funds are depleted. Select the combination of projects that yields the largest aggregate NS.

Special Topics

This next section discusses several topics that may be encountered in LCC analysis. Value engineering and sensitivity analysis are two additional ways of applying the life cycle costing procedures to evaluate project alternatives. Break-even analysis is used as an alternative technique to payback and can be used to test the sensitivity to fixed and variable costs. Deprecation is an incentive offered by the government to encourage business to invest. Deprecation can be an extremely complicated topic if all the tax laws are covered. In this section, deprecation is covered in its most basic form, which should be enough for most HVAC system evaluations. The final topic is a look at how some non-economic impacts can be evaluated determining the economic consequences.

Value Engineering

Separate from but related to economic analysis methods is a cost control technique referred to as *Value Engineering (VE)*. VE is a systematic evaluation procedure that attempts to analyze the functionality of building materials, systems, and equipment with the goal of achieving required functionality while simultaneously minimizing the total cost of ownership.

Do not confuse VE with reductions in a project's scope or quality to get the project into a predefined budget. Reducing initial costs at the sacrifice of quality, functionality or performance is simply "cost cutting," not VE.

Ideally, VE is not just everyone "cutting their prices" and subsequent profit margins. Low bidders are sometimes asked to arbitrarily reduce their price without reducing their offering. It should be noted that if a project is over budget by more than 15-20 percent you have to ask why the original cost estimator missed the mark by such a large amount.

When performed properly, VE can be a powerful tool for getting a project within budget. During the VE, process contractors often contact suppliers and request deletions or deductive alternates to the originally specified bill of materials. The hope is that by deleting all the fancy "bells and whistles," the client winds up with a comparable (equally functional) system at a lower installed cost. However, in reality often reducing energy-saving components or accessories to save installed costs is a losing proposition. Such is the case with an economizer on a packaged HVAC unit, for instance. On the other hand, if the cost reductions are purely aesthetic in nature the results may have no impact on the operating costs or functionality of the system or building. However, for example, if ceramic tile floors are selected in lieu of more elegant marble floors, the prospective tenants may not like the building as well and decide to relocate to what they perceive as a more upscale facility. Sometimes VE decisions are difficult to analyze, especially if they are primarily subjective in nature.

Normally the VE process is a team exercise involving all members of the project team from the architect down to the suppliers. Typical questions to be answered for each building component or system include:

- What is its intended purpose?
- How critical is it?
- How much does it cost?
- Are there other less-costly substitute materials that can be used to achieve the same results without sacrificing the required performance or degrading reliability, safety, or maintainability?

The goal of VE is to eliminate anything and everything that adds first-cost without sacrificing efficiency or functionality.

Major public works projects may be subjected to both VE and LCC analyses. Even though the two practices have different purposes, their effects on design alternatives are often interrelated. In some cases, VE can be used in conjunction with a LCC analysis when the selected LCC alternatives cannot be implemented without exceeding the project budget. In that case, VE can be utilized to reduce initial costs independent of those under consideration in a LCC analysis. If the VE effort results in sufficient reduction in initial costs, the resulting savings may allow certain project alternatives to be implemented without causing the project to go over budget, thus optimizing the overall cost-effectiveness of the entire project.

As mentioned previously, the evaluation of subjective (non-quantifiable) benefits is one of the most challenging aspects of conducting a VE or cost analysis. Factors such as aesthetics, occupant comfort, occupant productivity, satisfaction, and environmental impacts are often difficult to quantify. For instance, the restoration of a historic building may cost considerably more than simply demolishing it and constructing a new building in its place; however, the benefits of having a historical building may attract certain customers or tenants to a facility that may otherwise not be interested. These kinds of subjective factors are difficult to quantify and analyze.

Uncertainty and Sensitivity Analysis

A LCC analysis incorporates many assumptions. When the process of running all the numbers is complete, the final answer for the best decision may still not be obvious. Because the values assumed may impact the decision, sensitivity analysis should be considered. As an example, if a project has assumed an electric cost of $0.10 per kWh what will the results of the study be the same if the actual costs turn out to be $0.08 per kWh? Will the results change if the cost is actually $0.12 per kWh? The process of determining this impact is a sensitivity analysis.

There are many techniques in how to deal with project uncertainty and the sensitivity to assumptions. These can essentially be divided into to two groups, deterministic and probabilistic. Deterministic approaches take one variable that is in question and vary its value between an expected high and low value to evaluate the affect on the decision. The basic assumption of deterministic approaches is that only this one value will change. This assumption is often not the case and several items change simultaneously, as one can cause others to change. To address this situation probabilistic approaches are used. These methods use statistical analysis to determine the likelihood of multiple variables changing together. Probabilistic methods while more accurate are more complicated to compute. For most HVAC studies, the use of deterministic approaches will lead to appropriate decisions.

The basic procedure for a deterministic sensitivity analysis is to:

1. Determine which variables are of concern and the expected amount of change
2. Vary one of these variables at a time, in increments. I.E 5 percent or 10 percent at a time.
3. Recalculate the measures of evaluation (LCC, NS, SIR, IRR, PB, DPB)
4. Evaluate the results to determine if the decision should be modified
5. Document the decision for the owners analysis

Energy costs are one of the largest components of HVAC life cycle analysis and potentially one with the largest uncertainty. In private studies, it should be considered as one of the candidates for sensitivity analysis. However, for federal government studies it should be noted that the DOE energy price escalation rates and discount rates must be used.

Sensitivity analysis is an important step in presenting a complete picture for decision-making. It is a relatively simple process and requires little additional effort but results in a better final decision. However, since the actual chance of any of the scenarios being the actual reality is still unknown good engineering judgment is still required.

Breakeven Analysis

One method of determining both a form of payback and a sensitivity test is to do a break-even analysis. Break-even analysis is a common technique uses to evaluate industrial processes. A break-even analysis calculates the year by year fixed and variable costs and determines at what point in time the savings will cover the costs. In HVAC analysis, this amounts to finding when the savings in operating and maintenance costs will exceed the investment costs. As with the sensitivity analysis if the variable costs are varied then the change can be determined. Like payback calculations if the time required to recover the investment is within the owner's objectives the project is acceptable.

Break-even analysis can be done for a single system or when comparing two systems using the differentials. The equation below can be used for break-even when comparing two systems:

Equation 10

$$S = \Delta C$$

or:

$$[\Delta E + \Delta OM\ \&\ R + \Delta W] = [\Delta I + \Delta Rep + \Delta Res]$$

Where:

S	= Operational savings
Δ C	= Difference in investment costs
Δ E	= Energy cost difference
Δ OM&R	= Operating maintenance and repair cost difference
Δ W	= Water cost difference
Δ I	= Investment cost difference
Δ Rep	= Replacement cost difference
Δ Res	= Residual cost difference

All costs are in present value terms.

It is common to graph a break-even analysis to quickly visualize the time required to recover an investment. Figure 29 shows this process with a simple example. Unlike payback the break-even does provide a measure of future cost savings after the break-even point.

Determines the point at which variable and fixed cost savings exceed investment costs

$$S = \Delta C$$

$$[\Delta E + \Delta OM\&R + \Delta W] = [\Delta I + \Delta Rep + \Delta Res]$$

or where:

S	= Operational savings
Δ C	= Difference in investment costs
Δ E	= Energy cost difference
Δ OM&R	= Operating maintenance and repair cost difference
Δ W	= Water cost difference
Δ I	= Investment cost difference
Δ Rep	= Replacement cost difference
Δ Res	= Residual cost difference

All costs are in present value terms.

Figure 29

Break-Even Analysis

Depreciation

Depreciation is an advanced topic that many readers may find too detailed to be easily applied. Most complex analyses involving depreciation are likely to be performed by an accountant or tax professional.

Depreciation is an annual income tax deduction that allows the recovery of the cost or other basis of certain assets over the time the property is used, provided the asset has a useful life beyond the current tax year. Depreciation is an allowance for the wear and tear, age, deterioration, or obsolescence of the asset. Depreciation is considered an expense each year and may be used, within limitations, for tax purposes to offset income. Depending on the type of asset considered, depreciation expenses must be spread-out over several years. In the United States, the Internal Revenue Service (IRS) sets the guidelines that companies may use to calculate depreciation. Assets with different useful lives have different depreciation time (recovery) periods. The IRS defines the allowable recovery period for different types of assets ranging from 3 years to 50 years. For instance, an automobile and a computer both have 5-year recovery periods, meaning you can depreciate these over 5 years, while a commercial building has a recovery period of 39 years.

There are several generally accepted methods used for calculating depreciation.

1. Straight Line
2. Sum-of-Years-Digits
3. Double Declining Balance
4. Double Declining Balance w/Conversion to Straight Line
5. Modified Accelerated Cost Recovery System (MACRS)

Straight-Line Method

As the title suggests, straight-line depreciation method assumes that the loss in value of the asset is directly proportional to its age. A constant rate is used over the life of the asset. Straight-line depreciation may be calculated from the following formula:

Equation 11

$$d = \frac{C - C_L}{L}$$

Where:

d = annual depreciation amount

C = initial cost of asset

C_L = asset salvage value

L = life in years

Example 31: A piece of equipment is acquired for $10,000. The useful life of the equipment is ten years and the salvage value at the end of the useful life is estimated at $1,500. Calculate the annual depreciation using the straight-line method.

Year	Book Value (in dollars)	Depreciation Charge (in dollars)
0	10,000	0
1	9,150	850
2	8,300	850
3	7,450	850
4	6,600	850
5	5,750	850
6	4,900	850
7	4,050	850
8	3,200	850
9	2,350	850

Figure 30

Straight-Line Depreciation Schedule

$$d = \frac{10{,}000 - 1{,}500}{10} = \$850.00/\text{yr}\ .$$

The results may be tabulated to make the results more useful as shown in Figure 30.

Sum-of-Years-Digits Method

The sum-of-years-digits method is an accelerated method that allows for greater depreciation during the early life of the asset. The sum-of-year-digits (SOYD) is calculated as follows:

Equation 12

$$SOYD = \frac{L(L+1)}{2}$$

Where:

SOYD = Sum-of-year-digits

L = Life in years

The depreciation for year N is calculated as:

Equation 13

$$d = \frac{L - N + 1}{SOYD}(C - C_L)$$

Example 32: Using the same information from Example 31, calculate the depreciation using the SOYD method.

$$SOYD = \frac{10(10+1)}{2} = 55$$

The depreciation formula must be calculated ten times, once for each year. Year 1 is calculated as follows:

$$d_1 = \frac{L - 1 + 1}{55}(10000 - 1500) = \$1{,}545$$

The remaining years are calculated and tabulated as shown in Figure 31.

Year	# Years Remaining	End of Year Book Value	Depreciation Charge
0	-	$10,000	$0
1	10	$8,455	$1,545
2	9	$7,064	$1,391
3	8	$5,827	$1.236
4	7	$4,745	$1,082
5	6	$3,818	$927
6	5	$3,045	$773
7	4	$2,427	$618
8	3	$1,964	$464
9	2	$1,655	$309
10	1	$1,500	$155

Figure 31

Sum-of-Years-Digits Depreciation Schedule

Double-Declining Balance Method

The double-declining balance method is an accelerated method of depreciation with depreciation rate twice that of the straight-line method. The formula used is as follows:

Equation 14

$$d = \frac{2}{L} * \text{Book value}$$

Although the method is called "double-declining" with a rate of (2 / L), other rates may be used such as (1.5 / L). The particular rate chosen depends on the desired objective and must comply with IRS regulations. Typically, management prefers to recover their investment as rapidly as possible. This is why accelerated methods are often used. Accelerated methods allow faster depreciation in the earlier years. The IRS usually allows one change of depreciation methods during the life of the asset; therefore, many managers use the accelerated method until the point in time where the straight-line method becomes greater than the accelerated method.

Example 33: Using the same information from Example 31, calculate the double-declining balance depreciation.

The calculation must be performed ten times, once for each year. Year 1 is calculated as follows:

$$d_1 = \frac{2}{10} * \$10{,}000$$

Subsequent years are calculated using the corresponding book value. Results are tabulated below.

Year	# Years Remaining	End of Year Book Value	Depreciation Charge
0	-	$10,000	$0
1	10	$8,000	$2,000
2	9	$6.400	$1,600
3	8	$5,120	$1,280
4	7	$4,096	$1,024
5	6	$3,277	$819
6	5	$2,621	$655
7	4	$2,097	$524
8	3	$1,678	$419
9	2	$1,342	$336
10	1	$1,074	$268

Figure 32

Double-Declining Balance Depreciation Schedule

From the table you can see that with this method the asset is never fully written-off. In practice, management would be prudent to switch to the straight-line method when the depreciation amount falls below the straight-line method value. In our particular example, this occurs at the end of year 4. Because the depreciation amount for the double-declining method in $819 for year 5 and $850 each year in the straight-line method, management should switch to the straight-line method for years 5-10, or until the asset book value is reduced to the salvage value. The book value must not be allowed to drop below the salvage value as this would mean that excess depreciation is being taken.

Modified Accelerated Cost Recovery System (MACRS) Method

This method of calculating depreciation is used to recover the basis of most business and investment property placed in service after 1986. MACRS consists of two depreciation systems, the General Depreciation System (GDS) and the Alternative Depreciation System (ADS). Generally, these systems provide different methods and recovery periods to use in figuring depreciation deductions. IRS Publication 946 covers MACRS for assets placed into service after 1986. Assets placed in service prior to 1987 must be depreciated as outlined in IRS Publication 534.

To simplify the depreciation process, the IRS allows what is referred to as a Section 179 deduction. For the year 2001, this allowable deduction was $24,000 and will be increased each year under a pre-determined schedule. Section 179 states that up to $24,000 of assets, placed into service during 2001, may be deducted in the same year without having to depreciate them. If the amount of the asset exceeds this allowance, the balance may be carried-over to subsequent years until it is fully deducted. This rule was designed by the IRS to assist small businesses. Ultimately the manager will have to decide which of the various depreciation methods are most tax-efficient.

Since IRS regulations tend to be in a constant state of flux, we will not go into detail about the MACRS procedure here. If interested you should refer to the appropriate IRS Publications or consult a tax professional to ensure that you are complying with the latest tax regulations.

Non-Economic Evaluation

As was pointed out earlier, alternatives selected for projects can influence the productivity of the building occupants or improve the rent potential or building resale value. These numbers are hard to quantify. There are many studies currently being done to establish specific measures of improvement to changes in system parameters. As can be seen from Figure 33 the largest cost for a building owner is the cost of the personnel in the building. If even a small change can be made in the productivity of people it can be seen this can easily be overwhelm even large savings in energy costs.

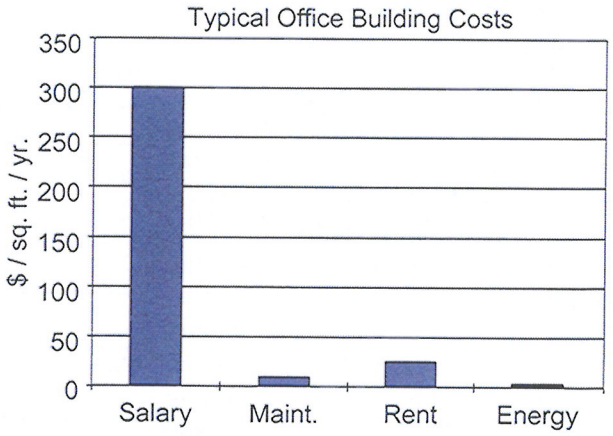


Figure 33

Costs to a Building Owner

Tools are available to demonstrate the potential savings to the owner, where the case is a tenant owner, a renting owner, or even the tenant. In each of these cases, the savings can significantly influence the decisions made. Figure 34 is an example of one of these spreadsheets.

Productivity Economic Analysis - Cost to Employer				
Building Area (sq. ft.):		20,000	Productivity *loss* due to	
Number of Employees:		125	poor thermal comfort,	
Avg. Occupancy Density:		160	absenteeism, etc. (%)	2
	(sq.ft/per.)			
Building Operating Costs:			Lost Productivity Cost:	
	Rent ($/sq.ft./yr.)	$15.00	($/sq. ft./per./yr.)	$3.90
	Utilities ($/sq.ft./yr.)	$1.50	Total Bldg.	$78,000
	Taxes ($/sq.ft./yr.)	$3.00		
	Total ($/sq.ft./yr.)	$19.50	Avg. Bldg. Const. Cost ($/sq.ft.)	$100.00
	Total Annual	$390,000		
Salary Costs:			HVAC System Inst. Cost ($/sq.ft.)	$10.00
	Hourly Pay:	$12.00	% of Total Bldg. Cost	10%
	Benefits (+30%)	$3.60		
	Total Hourly	$15.60	% Additional Upgrade Cost	50
	Total Annual (per person)	$31,200	Upgrade Cost	$5.00
	Total Annual	$3,900,000	Total HVAC System Inst. Cost ($/sq.ft.)	$15.00
	($ /sq.ft / person / yr.)	$195		
			ROI of HVAC Upgrade Cost	78%
Ratio of:	Salary To Bldg. Oper. Cost	10	Simple Payback Period (years)	1.28
	Salary To Annual Energy Cost	130		

Figure 34

Productivity Spreadsheet

Analysis Tools

LCC costing studies can involve the manipulation of many numbers. Several tools are available to reduce the drudgery of number crunching and help reduce calculation errors. This section looks at two methods and uses an example problem to demonstrate the use of a computerized calculation tool.

Spreadsheet Methods

Computers have made electronic spreadsheets a quick and easy way to calculate life cycle costing data. Many electronic spreadsheets even come with many of the economic formula as predefined functions. These formulas can be easily applied in a spreadsheet that can calculate the required economic criteria. With any calculation tool the tool only speeds calculation and reduces error, the user must still apply good engineering judgment in determining the inputs and evaluating the output.

Figure 35 is a sample of an electronic spreadsheet.

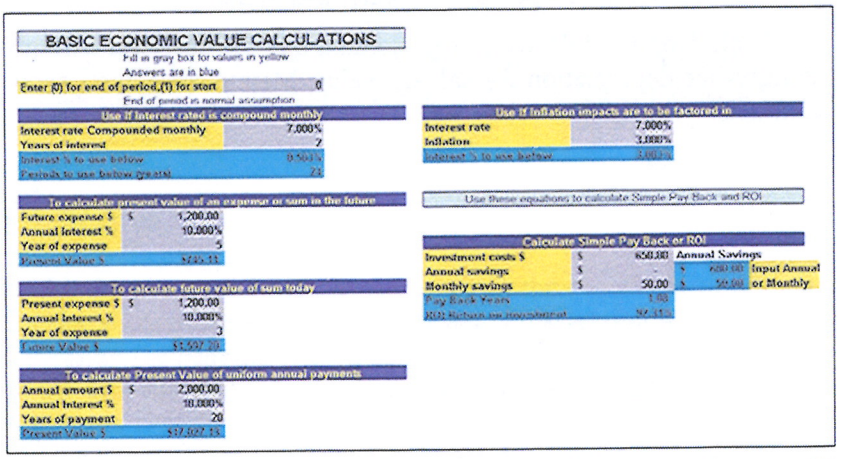


Figure 35

Economic Calculation Spreadsheet

Economic Analysis Software

The next step from an electronic spreadsheet is a computer economic analysis program. Computers have the advantage that the reports produced and the decision criteria evaluated can be much more detailed. In addition, because the data is quickly manipulated it is very easy to run various scenarios, for example to do a sensitivity analysis, in a very short period.

Two examples of these programs are mentioned here. First is the Carrier Economic Analysis program. This program is used for the example below. The program allows calculating the economic decision process for public or private studies. This program use the same formula described in this text to calculate the economic measures of present worth, cash flow, and payback. The advantage to this program is that it is linked to the HAP energy analysis program and the results of an energy study can be linked directly to the economic analysis program.

The second program is one available from the government that allows calculating life cycle costs, the BLCC (Building Life Cycle Analysis. This program is very similar to the Carrier Economic analysis program but has some special features that make it work well in calculating analysis for Federal government projects. One of these features is the program is linked to the DOE energy rate tables and fuel costs are computed automatically from his link.

Example Life Cycle Cost Analysis

The best way of demonstrating how these programs use the material described in the above text is with an example.

Example 34. A school has decided to put on a new addition and has three systems under consideration. One is a water-cooled centrifugal chiller, the second is a water-cooled screw chiller and the third is an air-cooled chiller. Since only the chiller is the purpose of this study it is decided that it is not necessary to include any of the other systems costs, only the differences between the three systems needs to be evaluated. The school will issue bonds to finance the project for 90 percent of the cost for 15 years. The current bond rate is 7.5 percent. The school wants the study done on a 20-year period. Escalation rates are assumed at 3 percent for electricity, 2.5 percent for labor, and 4 percent for water treatment.

Table 5 on the following page summarizes the cost data assembled by the engineer. Assume straight-line depreciation for salvage value. Maintenance costs shown in the table are for service contracts.

Table 5			
Item	**Chiller 1 W/C Centrifugal**	**Chiller 2 W/C Screw**	**Chiller 3 A/C Scroll**
Purchase Costs			
Chiller First Cost	$67,950	$58,410	$81,620
Cooling Tower	$12,320	$12,320	$0
CW pump and Piping	$4,410	$4,410	$4,410
Cond. Pump and piping	$3,675	$3,675	$0
Installation Costs			
Chiller	$23,730	$11,870	$14,300
Cooling Tower	$1,340	$1,340	$0
CW Pump and Piping	$2,520	$2,520	$2,520
Cond. Pump and Piping	$2,100	$2,100	$0
Energy Costs			
Electric Usage	$12,310	$13,920	$15,770
Electric Demand	$ 6,250	$ 5,872	$ 5,120
Natural Gas	$ 8, 198	$ 8, 198	$ 8, 198
Maintenance Costs			
Chiller	$ 3,000	$ 3,000	$ 2,500
Cooling Tower	$ 1,200	$ 1,200	$ 0
Water Treatment	$ 2,005	$ 2,005	$ 0
Replacements	$ 0	$ 0	$ 900 / yr 15

The first step in our analysis is to define the project. The required information is entered on the study input screen. The project is defined; this is a good place to enter the descriptive data and the overriding conditions we discussed at the beginning of this TDP. This project is for a school so this will be a public analysis. Remember this means deprecation and tax impacts are not considered. We then need to decide the type of decision. Since this is to add a chiller only one type can be used so this is a mutually exclusive decision. The study will be based on the time the unit is put into service making the base year the first year of our study. The length of the study is input as 20 years for this project. The final general input item is the discount rate, which was defined as the bonding rate of 7.5 percent.

Each alternative is defined as a case. The particulars for each alternative chiller system are entered as cases. General description of each chiller is entered on the design case general input form.

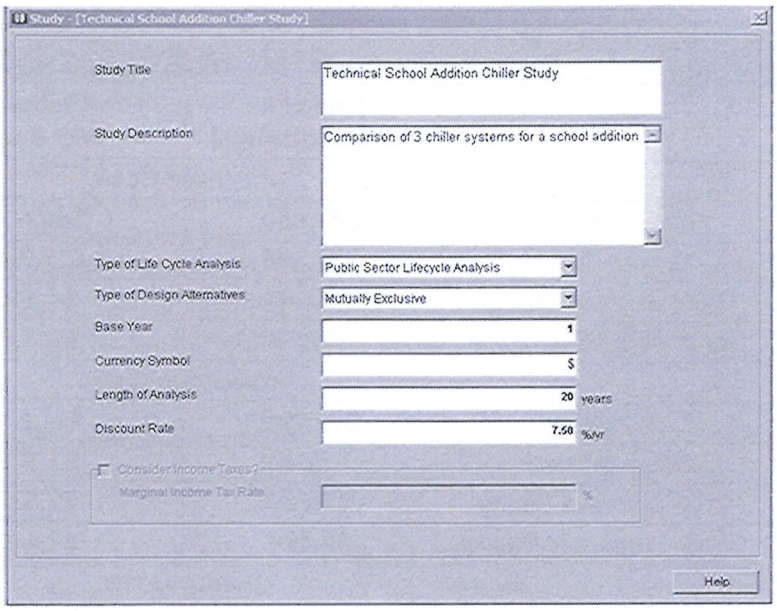


Figure 36

Study Input

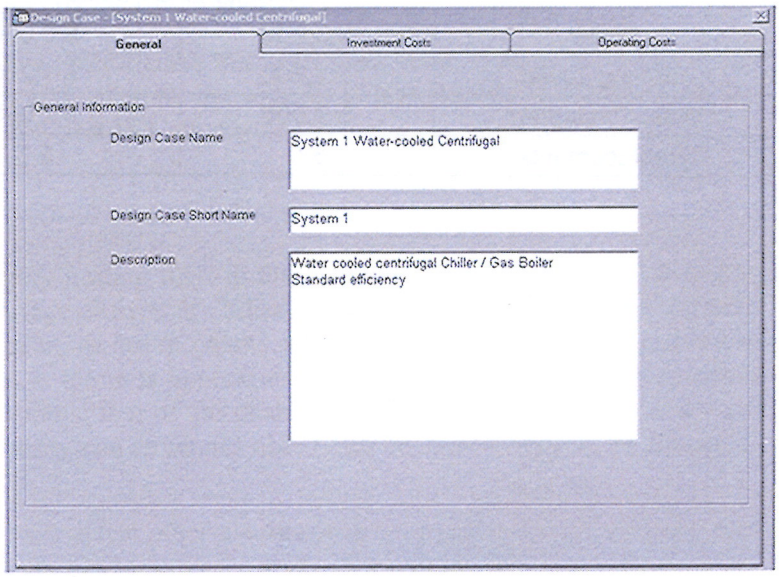
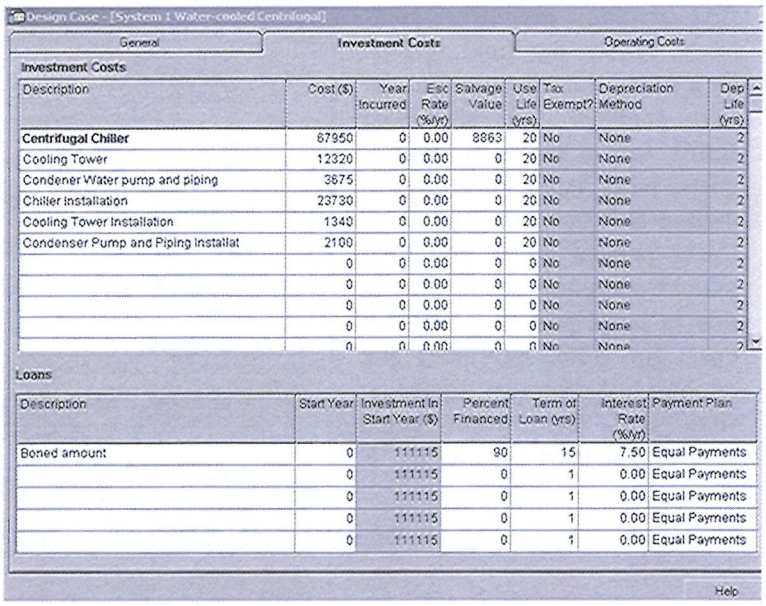


Figure 37

Case Input General

The data related to investment costs is entered on the case investment input data. All the data is input from the table above for the centrifugal chiller. Notice that the information on the chilled water pump and piping are not input. Because these are the same for each case it is not necessary to input this item. The equipment life needs to be entered from Figure 10. The life of the chiller is 23 years. Since the study is for 20 years the chiller will outlast the study, so in this case we decided to calculate a residual / salvage value. We divide the chiller first cost by 23 years for an annual cost of $2,954/ year; with 3 years left the salvage value is $8,863. The cooling tower and pump have a 20-year life so no residual value will be calculated for them.



Design Case - [System 1 Water-cooled Centrifugal]

General | Investment Costs | Operating Costs

Investment Costs

Description	Cost ($)	Year Incurred	Esc Rate (%/yr)	Salvage Value	Use Life (yrs)	Tax Exempt?	Depreciation Method	Dep Life (yrs)
Centrifugal Chiller	67950	0	0.00	8863	20	No	None	2
Cooling Tower	12320	0	0.00	0	20	No	None	2
Condener Water pump and piping	3675	0	0.00	0	20	No	None	2
Chiller Installation	23730	0	0.00	0	20	No	None	2
Cooling Tower Installation	1340	0	0.00	0	20	No	None	2
Condenser Pump and Piping Installat	2100	0	0.00	0	20	No	None	2
	0	0	0.00	0	0	No	None	2
	0	0	0.00	0	0	No	None	2
	0	0	0.00	0	0	No	None	2
	0	0	0.00	0	0	No	None	2
	0	0	0.00	0	0	No	None	2

Loans

Description	Start Year	Investment In Start Year ($)	Percent Financed	Term of Loan (yrs)	Interest Rate (%/yr)	Payment Plan
Bonded amount	0	111115	90	15	7.50	Equal Payments
	0	111115	0	1	0.00	Equal Payments
	0	111115	0	1	0.00	Equal Payments
	0	111115	0	1	0.00	Equal Payments
	0	111115	0	1	0.00	Equal Payments

Help

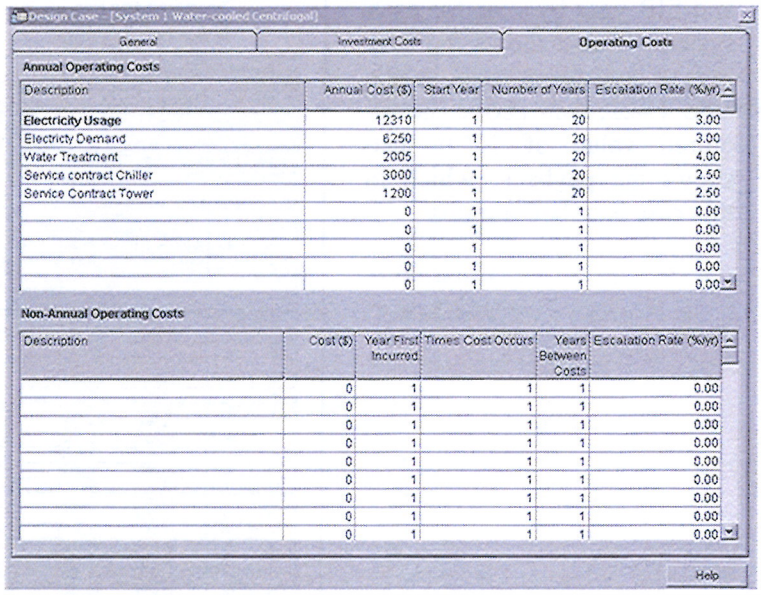
Figure 38

Case Input Investment

The investment costs are totaled in the loan section at the bottom of the screen and we need to make some decisions about how the project is financed. The school will bond the project at 7.5 percent rate for 15 years. The bonding or loan rate does not need to be the same as the discount rate for the general case, as it most likely would have been for a private study. The bonded amount will most likely be paid in equal payments. This completes the investment cost data for the centrifugal chiller.

Operating costs for the centrifugal chiller are entered on the operating cost screen. These include the electric use and demand charges, the annual service contracts, and the water treatment costs. An escalation rate for each of these items is also input here. The centrifugal chiller has no non-annual repair or replacements. When the scroll unit case is entered, the engineer has decided a $900 scroll compressor will be required in year 15.

The input data is repeated for the other chillers in the same fashion. This completes the input data and the reports can be calculated.



Design Case - [System 1 Water-cooled Centrifugal]

General | Investment Costs | Operating Costs

Annual Operating Costs

Description	Annual Cost ($)	Start Year	Number of Years	Escalation Rate (%/yr)
Electricity Usage	12310	1	20	3.00
Electricty Demand	6250	1	20	3.00
Water Treatment	2005	1	20	4.00
Service contract Chiller	3000	1	20	2.50
Service Contract Tower	1200	1	20	2.50
	0	1	1	0.00
	0	1	1	0.00
	0	1	1	0.00
	0	1	1	0.00
	0	1	1	0.00

Non-Annual Operating Costs

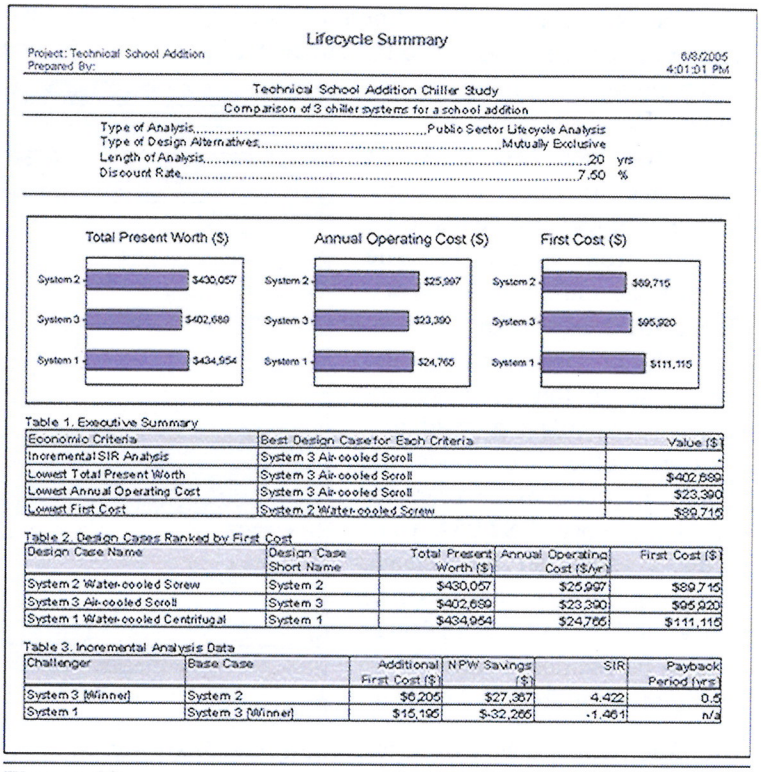
Description	Cost ($)	Year First Incurred	Times Cost Occurs	Years Between Costs	Escalation Rate (%/yr)
	0	1	1	1	0.00
	0	1	1	1	0.00
	0	1	1	1	0.00
	0	1	1	1	0.00
	0	1	1	1	0.00
	0	1	1	1	0.00
	0	1	1	1	0.00
	0	1	1	1	0.00
	0	1	1	1	0.00

Help

Figure 39

Case Input Operating

The first report is a summary of the life cycle costs. The first section, executive summary, shows the final results. Based on the assumptions of this analysis the air-cooled scroll, while higher in energy costs, wins based on an incremental SIR analysis and has a lower present worth and total annual operating costs. This is due in large part to the higher costs for water treatment and cooling tower service. Based on first cost the water-cooled screw is the least expensive.



Lifecycle Summary

Project: Technical School Addition
Prepared By:
6/8/2005
4:01:01 PM

Technical School Addition Chiller Study
Comparison of 3 chiller systems for a school addition

Type of Analysis: Public Sector Lifecycle Analysis
Type of Design Alternatives: Mutually Exclusive
Length of Analysis: 20 yrs
Discount Rate: 7.50 %

Table 1. Executive Summary

Economic Criteria	Best Design Case for Each Criteria	Value ($)
Incremental SIR Analysis	System 3 Air-cooled Scroll	-
Lowest Total Present Worth	System 3 Air-cooled Scroll	$402,689
Lowest Annual Operating Cost	System 3 Air-cooled Scroll	$23,390
Lowest First Cost	System 2 Water-cooled Screw	$89,715

Table 2. Design Cases Ranked by First Cost

Design Case Name	Design Case Short Name	Total Present Worth ($)	Annual Operating Cost ($/yr)	First Cost ($)
System 2 Water-cooled Screw	System 2	$430,057	$25,997	$89,715
System 3 Air-cooled Scroll	System 3	$402,689	$23,390	$95,920
System 1 Water-cooled Centrifugal	System 1	$434,954	$24,765	$111,115

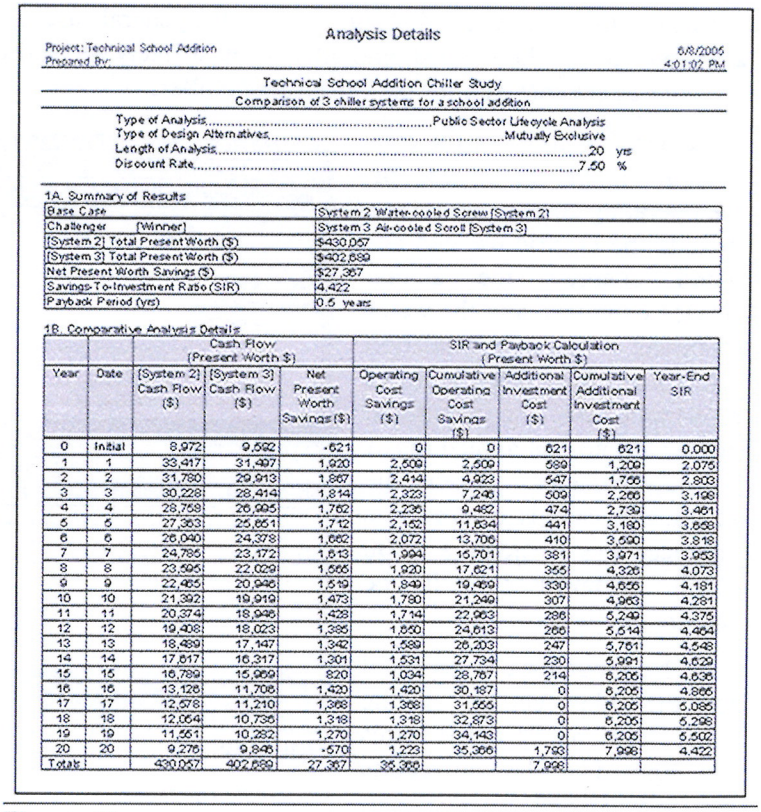
Table 3. Incremental Analysis Data

Challenger	Base Case	Additional First Cost ($)	NPW Savings ($)	SIR	Payback Period (yrs)
System 3 [Winner]	System 2	$6,205	$27,367	4.422	0.5
System 1	System 3 [Winner]	$15,195	$-32,265	-1.461	n/a

Figure 40

Life Cycle Summary Report

The second report details the present worth cash flow and SIR year by year for each system. It also shows the savings to investment ratio, in this case 4.422, well above the required value of 1. It also shows the payback, which in this case is only 6 months.



Analysis Details

Project: Technical School Addition
Prepared By:
6/8/2005
4:01:02 PM

Technical School Addition Chiller Study
Comparison of 3 chiller systems for a school addition

Type of Analysis: Public Sector Lifecycle Analysis
Type of Design Alternatives: Mutually Exclusive
Length of Analysis: 20 yrs
Discount Rate: 7.50 %

1A. Summary of Results

Base Case	System 2 Water-cooled Screw [System 2]
Challenger [Winner]	System 3 Air-cooled Scroll [System 3]
[System 2] Total Present Worth ($)	$430,057
[System 3] Total Present Worth ($)	$402,689
Net Present Worth Savings ($)	$27,367
Savings-To-Investment Ratio (SIR)	4.422
Payback Period (yrs)	0.5 years

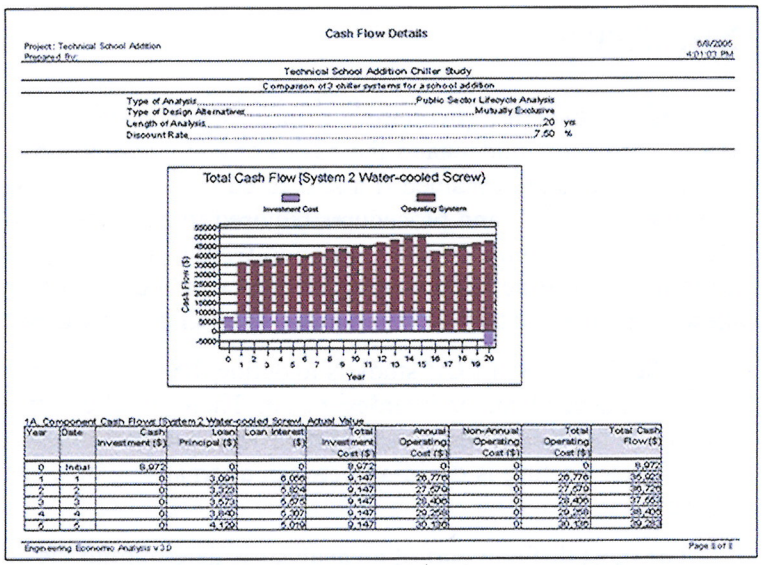
1B. Comparative Analysis Details

		Cash Flow (Present Worth $)			SIR and Payback Calculation (Present Worth $)				
Year	Date	[System 2] Cash Flow ($)	[System 3] Cash Flow ($)	Net Present Worth Savings ($)	Operating Cost Savings ($)	Cumulative Operating Cost Savings ($)	Additional Investment Cost ($)	Cumulative Additional Investment Cost ($)	Year-End SIR
0	Initial	8,972	9,592	-621	0	0	621	621	0.000
1	1	33,417	31,497	1,920	2,509	2,509	589	1,209	2.075
2	2	31,780	29,913	1,867	2,414	4,923	547	1,756	2.803
3	3	30,228	28,414	1,814	2,323	7,246	509	2,266	3.198
4	4	28,759	26,995	1,762	2,236	9,482	474	2,739	3.461
5	5	27,363	25,651	1,712	2,152	11,634	441	3,180	3.658
6	6	26,040	24,378	1,662	2,072	13,706	410	3,590	3.818
7	7	24,785	23,172	1,613	1,994	15,701	381	3,971	3.953
8	8	23,595	22,029	1,566	1,920	17,621	355	4,326	4.073
9	9	22,465	20,946	1,519	1,849	19,469	330	4,656	4.181
10	10	21,392	19,919	1,473	1,780	21,249	307	4,963	4.281
11	11	20,374	18,946	1,428	1,714	22,963	286	5,249	4.375
12	12	19,408	18,023	1,385	1,650	24,613	266	5,514	4.464
13	13	18,489	17,147	1,342	1,589	26,203	247	5,761	4.548
14	14	17,617	16,317	1,301	1,531	27,734	230	5,991	4.629
15	15	16,789	15,969	820	1,034	28,767	214	6,205	4.636
16	16	13,126	11,706	1,420	1,420	30,187	0	6,205	4.866
17	17	12,578	11,210	1,368	1,368	31,555	0	6,205	5.085
18	18	12,064	10,736	1,318	1,318	32,873	0	6,205	5.298
19	19	11,561	10,282	1,270	1,270	34,143	0	6,205	5.502
20	20	9,276	9,846	-570	1,223	35,366	1,793	7,998	4.422
Totals		430,057	402,689	27,367	35,366		7,998		

Figure 41

Life Cycle Analysis Details

The third report details the cash flow by each individual cost component and for each system.



Cash Flow Details

Project: Technical School Addition
Prepared By:
6/8/2005
4:01:07 PM

Technical School Addition Chiller Study
Comparison of 3 chiller systems for a school addition

Type of Analysis: Public Sector Lifecycle Analysis
Type of Design Alternatives: Mutually Exclusive
Length of Analysis: 20 yrs
Discount Rate: 7.50 %

Total Cash Flow (System 2 Water-cooled Screw)

1A. Component Cash Flows (System 2 Water-cooled Screw, Actual Value)

Year	Date	Cash Investment ($)	Loan Principal ($)	Loan Interest ($)	Total Investment Cost ($)	Annual Operating Cost ($)	Non-Annual Operating Cost ($)	Total Operating Cost ($)	Total Cash Flow ($)
0	Initial	9,972	0	0	9,972	0	0	0	9,972
1	1	0	3,091	6,056	9,147	26,776	0	26,776	35,923
2	2	0	3,323	5,824	9,147	27,579	0	27,579	36,726
3	3	0	3,573	5,574	9,147	28,406	0	28,406	37,553
4	4	0	3,840	5,307	9,147	29,258	0	29,258	38,405
5	5	0	4,129	5,018	9,147	30,136	0	30,136	39,283

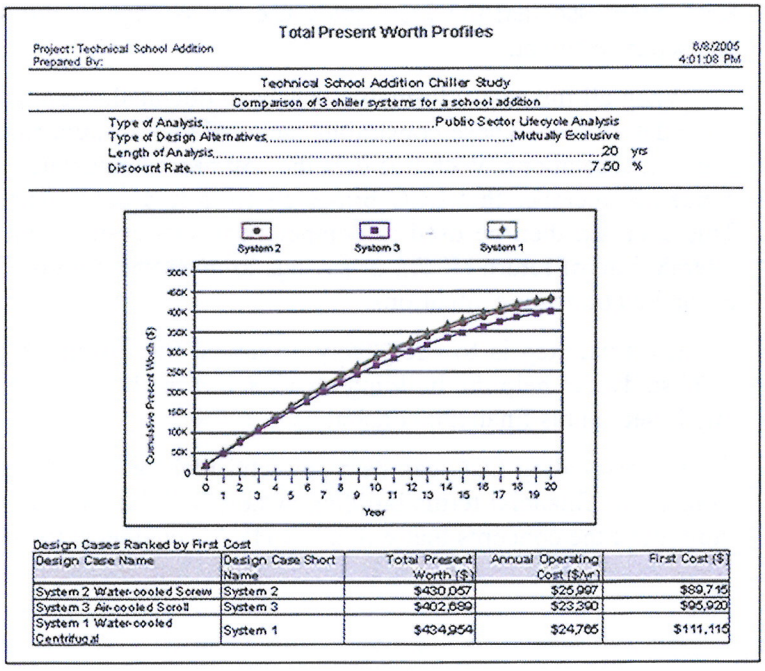
Engineering Economic Analysis v 3.0
Page 3 of 5

Figure 42

Cash Flow Details

The final report shows the total present worth and charts the cumulative present worth of each system for the entire study period.

While this study indicated that the air-cooled scroll chiller was better, this may not be true on a different project. Had some of the assumptions of this study been different or the system requirements different, one of the other alternatives might be the winner instead. This is the reason each project needs to be looked at based on the requirements and economic conditions for that specific project.



Total Present Worth Profiles

Project: Technical School Addition
Prepared By:
6/8/2005
4:01:08 PM

Technical School Addition Chiller Study
Comparison of 3 chiller systems for a school addition

Type of Analysis: Public Sector Lifecycle Analysis
Type of Design Alternatives: Mutually Exclusive
Length of Analysis: 20 yrs
Discount Rate: 7.50 %

Design Cases Ranked by First Cost

Design Case Name	Design Case Short Name	Total Present Worth ($)	Annual Operating Cost ($/yr)	First Cost ($)
System 2 Water-cooled Screw	System 2	$430,057	$25,997	$89,715
System 3 Air-cooled Scroll	System 3	$402,589	$23,390	$95,920
System 1 Water-cooled Centrifugal	System 1	$434,954	$24,765	$111,115

Figure 43

Total Present Worth Report

Summary

Energy concerns, government mandates, and sustainable design have made it imperative that HVAC engineers understand the basics of life cycle costing. The techniques are relatively easy and best results are obtained if a structured procedure is followed. This TDP presented the basic concepts, formulas, and procedures required to perform life cycle cost studies for most projects. However, this is only an introduction to what can be a complicated topic; some projects will require even more detailed costing studies with more in-depth tax and financial analysis. When these more detailed studies are required specialists in financial studies should be brought in.

The first step in LCC study is to define the project and the type of alternatives: mutually exclusive, independent, or interdependent. Then the alternatives that meet the design constraints need to be identified and which of the five types of decision is required. Remember that the goal of life cycle costing is deciding between alternatives, only included data that is different and significant.

The most difficult part of an analysis is determining the cost of owning and operating the system. Many sources are available from which to obtain this information. This TDP provided guidance on the data and sources for each of these cost categories. However, determining what should be included and the best sources for any given project require good engineering judgment. Remember also that the LCC study use the savings in future operating costs to justify the increased investment.

When all the cost information has been obtained, the financial constraints of the owner need to be determined. These constraints included the discount rate, study period, inflationary affects, and cost escalations. With this data the cost can be calculated at a point in time, present, future or annual. Remember that LCC brings all costs to a common time period for a valid comparison. This data can then be used to compute financial comparison tools like payback, present worth, internal rate of return (IRR), or savings to investment ratio (SIR). Each comparison tool has appropriate application situations.

The final step is to adequately document the results. A properly prepared and documented LCC study can help the building owner select the best system for the specific needs of his building; based on his financial constraints.

Understanding LCC can be a powerful tool for HVAC engineers to justify engineering decisions in the financial terms building owners both public and private want to know. This TDP has introduced the concepts that will allow HVAC engineers to "talk their talk."

Work Session 1

1. Define the following terms:

   Life Cycle Period:

   _____

   Discounting:

   _____

   Compounding:

   _____

2. Which of the following variables are required to calculate the Future Value *(FV)* of a single payment amount?

   a) Simple Payback Period
   b) Discount Rate, *(d)*
   c) Initial Investment Amount, *(PV)*
   d) Interest Rate, *(i)*
   e) Annuity Value, *(A)*
   f) Number of Periods, *(N)*

3. A bank offers you two interest rates for your savings account. The first rate: 7.50 percent compounded annually. The second rate: 7.40 percent compounded monthly. Which rate yields the higher return at the end of one year? Why (show your work)?

   _____

   _____

   _____

   _____

4. True or False? The Present Value (PV) of a series of cash flows occurring over time will be less than the Future Value (FV)? _____.

   Why?_____

   _____

5. Calculate the Future Value (FV) of a $2,000.00 periodic annual investment at an interest rate of 8 percent, compounded monthly over a period of 20 years.

   _____

   _____

6. What are the five types of decisions between alternatives that are made in life cycle costing studies?
   1. _____
   2. _____
   3. _____
   4. _____
   5. _____

7. True or False. When the affects of inflation are included the discount rate is described as the real rate and the dollars are said to be in current dollars.

8. Assuming a business has a MARR of 7 percent and inflation is assumed to be 2.5 percent. The business will need to accumulate $250,000.00 to replace a system in 15 years. How much is needed in today's dollars to have the $250,000 (show your work)?

   _____

   _____

   _____

   _____

9. A building owner wants to compare the LCC electric cost of three systems, system, the current system, is $14,500 / year, system 2 is $13,750 / year and system 3 is $12,500. If the owner is willing to break-even in 10 years what is the most he can spend today if electricity is expected to increase in cost at 3.5 percent per year and the MARR is 8 percent?

   _____

   _____

   _____

   _____

10. A contractor proposes to install an economizer on an existing packaged rooftop unit. The installed cost of the economizer is $1,500. It is estimated that the economizer will save $25/month in energy costs. Assume the rooftop unit will last ten more years before it needs replacing. The building owner can yield 7.50 percent return (compounded monthly) on a bank money market fund. Should the owner purchase the economizer or deposit the $1,500 into her bank account (show your work)?

11. What is MARR?

12. List four methods of determining residual value.
    1. _____
    2. _____
    3. _____
    4. _____

13. Some costs included in investment costs include first cost, capital replacement costs, residual value, taxes and finance costs. True or false.

14. Electricity is frequently billed based on two components _____ and _____.

15. What can best be seen in looking at a cash flow analysis?

Work Session 2

1. Define the following terms:

   Cost Escalation: _____

   SIR Method: _____

   IRR Method: _____

   LCC Method: _____

   NS Method: _____

2. Define Return on Investment (ROI) in simple terms:

   _____

   _____

3. Define *Simple Payback* in simple terms:

   _____

4. Given a $3,500 annual investment amount (annuity) and a 2.5 percent annual rate of inflation (escalation) with a discount rate of 8 percent for twenty-five years, calculate the present value (PV).

   _____

   _____

5. An engineer is trying to decide between using a heat pump or a gas-fired HVAC system. Assume the interest rate is 10 percent. The table below lists the associated costs and useful lives of both alternatives. Using the Annual Cost Method determine which alternative is best (show your work).

Alternative	A (heat pump)	B (gas heating)
Useful life	15 years	18 years
Installed Cost	$10,000	$12,500
Annual Operating Cost (energy + maintenance)	$3,000	$2,500

6. An engineer is trying to decide if an airside economizer on a packaged rooftop unit (RTU) is cost-effective. The economizer provides free cooling when the outdoor conditions are favorable. If the economizer is not used the compressor must run many more hours per year resulting in an earlier failure and subsequent replacement of the compressor in year 8. Assume the interest (discount) rate is 10 percent and the escalation rate for annual operating and maintenance costs is 4 percent. Neglect the costs for water and assume a zero salvage value for both alternatives. The table below lists all required data for both alternatives. Using the LCC method, determine the most favorable alternative (show your work).

Alternative	Base Case (No Economizer)	A (With Economizer)
Useful life	15 years	15 years
Installed Cost	$15,000	$16,500
Annual Operating Cost (energy)	$3,500	$2,625
Annual Maintenance Cost	$1,500	$1,500
Capital Replacement Cost (replace compressor at end of year 8)	$2,000	N/A
Salvage Value	N/A	N/A

7. A building owner is considering adding a variable frequency drive (VFD) to a chilled-water pump to save energy. From a previously conducted energy analysis estimate, the following cost data has been collected:

Year	Annual Energy Cost w/o VFD	Annual Energy Cost with VFD	Annual Energy Savings with VFD
1	$1050	$840	$210
2	$1103	$882	$221
3	$1158	$926	$232
4	$1216	$973	$243
5	$1276	$1021	$255
Total	$5803	$4642	$1161

Assume that the total cost to purchase and install the VFD is $3,500, and that the building owner can borrow money from the bank at an interest rate of 8.5 percent, compounded annually. Using the IRR method, calculate the IRR for each alternative and decide which alternative is preferred (show your work).

6. Referring to question 5, calculate the Net Savings (NS).

Can the NS method be used in lieu of the LCC method? If so why, if not why not?

8. An architect is trying to determine the optimal glass type for a new building. Various types of glass are available; single pane, double-pane clear and double-pane, tinted. The associated installed and energy costs present values are summarized in the table below. Using the incremental SIR method, determine which alternatives are economically justified and determine which alternative is most cost-effective (show your work).

Design Alternative	Glass Type	Initial Cost $ (PV)	Energy Cost (life) $ (PV)
A	Single-Pane	$50,250	$150,750
B	Double-Pane	$65,850	$115,200
C	Double-Pane Tinted	$70,500	$100,750

9. A 20-year old piping system leaks water. Repairs must be made frequently to keep the system in operation. Annual OM&R costs average $15,000. The annual cost of the wasted water is $1,000. The cost to replace the entire piping system is $175,000. The typical life of a water piping system is approximately 30 years. Assume an escalation rate of 4 percent for all annual, recurring costs and a discount rate of 8 percent. Should the piping system be replaced immediately or should we wait 10 more years to replace it and incur the annual OM&R expenses? Select an appropriate economic analysis method and show your work below.

10. Three possible efficiency levels are being considered for a replacement packaged rooftop unit (RTU). Given the following cost data, decide on an appropriate economic analysis method and justify which system is most cost-effective (show your work). If required, use an escalation rate of 4 percent for all recurring costs and a discount rate of 6 percent.

Alternative	RTU-A	RTU-B	RTU-C
EER	9.5	10.5	12.0
Installed Cost	$17,965	$19,870	$21,050
Annual Energy Cost	$2,250	$2,000	$1,750
Annual OM&R Cost	$1,000	$1,000	$1,000

Notes:

Work Session 1 Answers

1. **Life Cycle Period**: The time of consideration over which the economic analysis will be performed. Often tied to the building owner's plans to retain ownership of the building or may correspond to the estimated useful life of the building or building systems.

   Discounting: An economic analysis technique that converts cash flows, which may occur at different time periods in the future, to an equivalent amount at a common point in time (Present Value)

   Compounding: An economic analysis technique that calculates the growth in value of an initial investment amount, over time, based on an assumed interest rate and includes the effects of accrued interest.

2. c, d, and f

3. Use Eq. A1; **FV = PV (1 + *i*)N;** Be sure (*i*) corresponds to number of compounding periods (*N*)

   Since it was not given, assume a value for PV, say $1,000, therefore:

   First rate: FV = 1,000 $(1.075)^1$ = $1,075.00

   Second Rate: FV = 1,000 $[1 + (.074/12)]^{12}$ = $1,076.56; therefore the second rate is preferred.

4. True because discounting (inflation) erodes the value of money over time. The nominal discount rate, *r*, should be used, which accounts for the combined effects of discounting and inflation.

5. Using Equation A3:

$$FV = 2000/12\left[\frac{1+(.08/12)^{12x20}-1}{(.08/12)}\right] = 166.67\left[\frac{3,9268}{.00667}\right] = \$98,122.90$$

   Notice that *A* and *i* are divided by 12 and *N* is multiplied by 12 to convert into monthly terms.

6. 1) Accept or reject
   2) Optimize a design or efficiency
   3) Determine the optimal building system type
   4) Determine the optimal combination of interdependent systems
   5) Rank order independent competing projects

7. False

8. Use Equation A8 to determine the nominal rate, 4.39% Then use equation A2 to discount FV to PV: PV = FV $[1 / (1 + i)^N]$ = 250,000 x $[1 / (1 + 0.0439)^{15}]$ = $131,237

9. Find the difference in systems 2 and 3 over the current system, $750 and $2000 respectively. Then use the Modified Present value formula, Equation A7:

$$UPV^* = A_1 * \left(\frac{1+e}{i-e}\right) * \left[1 - \left(\frac{1+e}{1+i}\right)^N\right]$$

Therefore:

For System 2 compared to 1:

$$UPV^* = \$750 * \left(\frac{1+0.035}{0.80-0.035}\right) * \left[1 - \left(\frac{1+0.035}{1+0.80}\right)^{10}\right] = \$5979.19$$

For System 3 compared to 1:

$$UPV^* = \$2000 * \left(\frac{1+0.035}{0.80-0.035}\right) * \left[1 - \left(\frac{1+0.035}{1+0.80}\right)^{10}\right] = \$15{,}944.15$$

10. Since the owner reinvests the monthly savings ($25) at the same bank interest rate, 7.5%: *Economizer*: use uniform compound amount (UCA) formula (Eq. A3);

$FV = A\left[\frac{(1+i)^N - 1}{i}\right]$; be certain ($i$) corresponds to *(N)*; $FV = A\left[\frac{(1+i)^N - 1}{i}\right]$

Money market: use the FV formula (Eq.3); FV = PV $(1 + i)N = \$1500\ (1 + 0.075)10 = \$3092$, therefore the economizer is the most cost-effective alternative.

11. Minimum Attractive Rate of Return (MARR) is the lowest acceptable rate of return on an investment as determined by the investor.

12. 1) Straight line method
    2) Deprecation Book Value
    3) Scrap Value
    4) Resale value

13. True

14. Usage, Demand

15. Years when outflow exceeds income from savings

Work Session 2 Answers

1. **Cost Escalation:** the rate of change of costs over time, may corresponds to the rate of inflation or some other benchmark.

   SIR Method: a supplemental cost analysis method often used by public sector entities such as municipalities and government agencies. The savings-to-investment ratio (SIR) is equal to either the ratio of present value savings to present value investment costs or the ratio of annual savings to annual investments.

   IRR Method: a *relative* cost analysis method usually used to compare two or more investment alternatives. If the calculated IRR > MARR, the alternative is economically justified. The alternative with the greatest IRR is the most favorable investment.

   LCC Method: a comprehensive method that accounts for all costs incurred and benefits received. This includes the costs to acquire, design, construct, operate, maintain and subsequently dispose of the facility or system. All of these costs are then discounted to their present value (PV) terms.

   NS Method: a supplementary economic cost analysis method closely related to the LCC method. The objective of the NS method is to demonstrate that the incremental investment (of the alternative cases over the base case) is justified based on operational costs savings alone.

2. An economic analysis technique that determines the financial gain associated with an investment of capital. ROI is calculated by dividing the net annual cash flow by the investment amount, expressed in percentage terms.

3. An economic analysis technique that indicates the number of periods (usually years) necessary to recover an investment of capital, without consideration to the time value of money.

4. Use the modified uniform present value (UPV) formula with cost escalation (Eq.A5):

$$PV = A_0\left(\frac{1+e}{1-e}\right)\left[1-\left(\frac{1+e}{1+i}\right)^N\right]$$

$$3{,}500\left(\frac{1+0.025}{0.08-0.025}\right)1-\left[\frac{(1+0.025)^{25}}{1+0.08}\right] = \$47{,}570$$

5. To perform an Annual Cost analysis we convert all costs to an annualized basis neglecting inflation and cost escalation and then solve the uniform cost recovery (UCR) formula (Equation A6) using the installed costs and useful lives, then add these values to the known annual costs as follows:

$$EUAC_A = 10{,}000\left[\frac{0.10(1+0.10)^{15}}{1+0.10^{15}-1}\right]+3{,}000 = \$4{,}315$$

$$EUAC_B = 12{,}500\left[\frac{0.10(1+0.10)^{18}}{1+0.10^{18}-1}\right] + 2{,}500 = \$4{,}024$$

Therefore Alternative B (gas heating) is preferred due to the lower annual cost.
NOTE: The primary advantage of this method is alternatives may have different economic lives.

6. Solution: We will use the LCC formula (Equation 1):

$$LCC = I + R + E + W + OM\ \&\ R - RV$$

All annual recurring costs must be escalated over their useful lives then discounted back to PV terms. All PV amounts are then summed to arrive at total LCC. Since there is an escalation rate for the annual operating and maintenance costs we will use Equation 10 to discount them. For the capital replacement cost (year 8) we simply use the PV equation (Equation. 5) from Section 1.

$$PV = FV * \left(\frac{1}{(1+i)^N}\right) \quad \text{(Equation A2)}$$

$$PV = A_0\left(\frac{1+e}{1-e}\right)\left[1-\left(\frac{1+e}{1+i}\right)^N\right] \quad \text{(Equation A5)}$$

Results are tabulated below:

Alternative	Initial Investment Cost (already in PV)	Capital Replacement Cost (replace compressor in year 8)	Annual Energy Cost (PV)	Annual OM&R
Base Case (No Economizer)	$15,000	$933	$34,511	$14,791
A (with Economizer)	$16,500	$0	$25,884	$14,791

Therefore, the economizer cost is justified because the LCC is less that the base case.

7. The IRR is calculated by computing the equivalent interest rate that will make the present value of all cash flows (inflows & outflows) from the investment equal to the investment cost. This is a trial-and-error method assuming values for (i) that make the investment amount equal to savings amount. Use Equation 6 with the assumed value of i.

$$PV = \frac{C_1}{(1+i)^1} + \frac{C_2}{(1+i)^2} + \frac{C_3}{(1+i)^3} + \ldots\ldots + \frac{C_N}{(1+i)^N}$$

Assume i = 10%

$$p = \frac{C_1}{(1+i)^1} + \frac{C_2}{(1+i)^2} + \frac{C_3}{(1+i)^3} + \ldots\ldots + \frac{C_N}{(1+i)^N}$$

This is considerably below the installed cost of $3,500. We could try a lower value for i, however we already know that the bank pays 8.5 percent interest on the money and since we are so far away from $3,500 using i =10 percent we can end the analysis now and conclude that the VFD is NOT a good investment compared to putting the money in the bank.

Actually, we could have saved time and effort by first looking closer at the cumulative annual savings amounts. Over five years this only amounts to $1,161. With an installed cost of the VFD of $3,500, this means that it would take more than 15 years to payback, an unrealistic proposition.

8. Yes, to perform a NS calculation you are effectively first calculating the LCC for each alternative. Both methods (NS & LCC) will yield comparable and consistent results.

9. The savings-to-investment ratio (SIR) is equal to the ratio of the present value (PV) savings to the PV investment costs. The tabulated values are already in terms of PV so no discounting is required. Since there can only be one type of glass selected this means that the choices are *mutually exclusive*. Do not make the mistake of simply dividing the savings by the investment for each alternative. This is incorrect. For mutually exclusive alternatives *you must use an incremental analysis method* to analyze all alternatives. The base case will be Alternative A (single-pane) since it has the lowest initial cost and the highest operating costs. Alternatives B & C will then be incrementally compared to see if the incremental costs between alternatives may be justified by their incremental savings. The SIR is simply the change in incremental savings divided by the incremental investment cost for each alternative as tabulated below.

Design Alternative	Glass Type	Total LLC $ (PV)	Δ Cost $ (PV)	Δ Savings $ (PV)	Incremental SIR
A	Single Pane	201,000	0	0	N/A
B	Double Pane	181,050	15,600	35,550	2.28
C	Double Pane Tinted	171,250	4,650	14,450	3.11

From the results above we see that Alternate B saves $35,550 over the base case at an additional cost of $15,600 resulting in an SIR of 2.28, therefore Alternative B is cost effective over the base case, and therefore the base case is eliminated from further consideration.

Next we move to Alternate C, which results in an incremental savings of $14,450 over Alternate B at an incremental cost of $4,650 resulting in an SIR of 3.11. Therefore, Alternate C (double-pane, tinted) has the highest incremental SIR and is the preferred alternative.

Alternate B is also cost-justified since it also has an SIR > 1.0. However, Alternate C yields a higher savings for the incremental investment. As a check, we should also refer to the Total LCC values for each alternative. Notice the Total LCC for Alternate C is the lowest, which is consistent with the results of the incremental SIR method.

10. This problem is classified as an accept / reject decision. Since annual costs are given along with an escalation rate, we can use the LCC method by calculating the PV of each alternative. The alternative with the lowest LCC is the preferred alternative.

Since the existing piping is 20 years old, it is 2/3 of the way through its normal service life. The real question is do we replace it now or wait 10 more years? Let's set-up our design alternatives:

Base case: Do nothing, that is continue to repair and maintain the existing piping system for 10 more years, then replace it.

Alternative A: Replace the piping system now. This eliminates the annual OM&R and water costs.

We use the LCC (Equation 1) as follows:

$$LCC + I + R + E + W + OM\&R - RV$$

Where:

I = capital investment costs

R = capital replacement costs

E = energy costs

W = water costs

OM&R = operating, maintenance & repair costs

RV = residual value (salvage less disposal costs)

Let's tabulate the inputs for both cases.

Alternative	Economic Study Period	Installed Cost	Replacement Cost *R*	Annual Energy Cost *E*	Annual Water Cost *W*	Annual OM&R	Salvage Value *RV*
Base Case (do nothing)	10 years	$0	$0	N/A	$1,000	$15,000	N/A
A (replace piping)	10 years	$175,000	$0	N/A	$0	$0	neglect

Since annual, recurring costs are escalating each year we will allocate them over the economic study period then discount them back to PV terms. Since they are annual we can simply add them together ($15,000 + 1,000 = $16,000). The installation cost, *I* for Alt. A is already in PV terms. We will use Eq.A8 and solve for the PV.

$$FV = A\left[\frac{(1+i)^N - 1}{i}\right]$$

Since the LCC of Alternative A is $175,000, the most cost-effective decision is to do nothing for 10 years, that is continue to operate the existing system and incur the higher OM&R costs. Then replace the piping at the end of its useful life of 20 years.

In addition to the quantitative analysis above, there are subjective considerations that must be made for this type of situation. For instance, what are the repercussions if the piping system fails? Will it flood the building possibly damaging furnishings, computers, and important

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files? This is a difficult scenario to evaluate because you may not know the probability of occurrence and costs may depend on what insurance coverage the owner has to cover catastrophic losses such as this scenario.

In addition, advanced methods exist for analyzing uncertainty. These methods involve a sensitivity analyses and probabilities. Those types of methods are beyond the scope of this document; however, users interested in learning more about these advanced methods should refer to the reference section at the end of this document.

11. This is an *optimize design or efficiency* decision. The optimum efficiency level for a building or building system will be the one that minimizes life cycle costs (LCC) while maximizing the net savings (NS). For this type of decision, you should use either the LCC or NS methods and should *not* use the SIR, IRR or Simple Payback methods as they may yield inconclusive results. We will use the LCC method. Refer to the previous question solution for appropriate equations. Since the economic analysis period is not given we will assume a useful life of 15 years, which corresponds to the ASHRAE guidelines for service lives as shown in Figure 10.

$$LCC_A = \$3{,}250\left(\frac{1+0.04}{0.06-0.04}\right)\left[1-\left(\frac{1+0.04}{1+0.06}\right)^{15}\right]+\$17{,}965=\$59{,}966$$

$$LCC_B = \$3{,}000\left(\frac{1+0.04}{0.06-0.04}\right)\left[1-\left(\frac{1+0.04}{1+0.06}\right)^{15}\right]+\$19{,}870=\$58{,}641$$

$$LCC_C = \$2{,}750\left(\frac{1+0.04}{0.06-0.04}\right)\left[1-\left(\frac{1+0.04}{1+0.06}\right)^{15}\right]+\$21{,}050=\$56{,}590$$

Therefore, Alternate C with an EER of 12.0 and the lowest LCC is the most cost-effective alternative.

Appendix A – Economic Formula

This section explains common economic formula used to calculate the value in time that accounts for the time value of money. Since the value of an investment changes over time it is useful to be able to convert costs that occur during the life cycle period to a common point in time. Examples are provided with each, which demonstrate the use of the formula.

Future Value (Compounding)

The future value *(FV)* of a present sum of money *(PV)* may be determined using formula A1. Compounding occurs when the original principal amount is invested at an interest rate for a period of time. The total amount accumulated at the end of the investment period consists of the original principal amount plus accrued interest.

To compute the future value *(FV)* of any investment amount *(PV)* at an interest rate *(i)* over *(N)* number of periods, the following formula may be used:

Equation A1

$$FV = PV * (1 + i)^N$$

Where:

FV = Future Value
PV = Present Value
i = interest or discount rate per period
N = Number of periods

Example A1: A building owner has $500 now, which he wishes to place in a bank account to cover maintenance expenses 5-year in the future. The account pays 7 percent interest, compounded yearly. Calculate the future value (FV).

$$FV = \$500 * (1 + 0.07)^5 = \$701.28$$

At the end of the first year the owner will have accumulated $535, which is $35.00 interest plus the original principal of $500. If the owner leaves his or her money in the account for another year, the account balance will grow to $572.45. An additional $2.45 has accrued over and above the first year's interest because the account has accumulated (compounded) interest on interest. This trend will continue as long as the money is left in the account.

It is often helpful to draw a time line when analyzing time value of money problems. This gives you a visual tool, which makes it easier to see the expenditures as they occur.

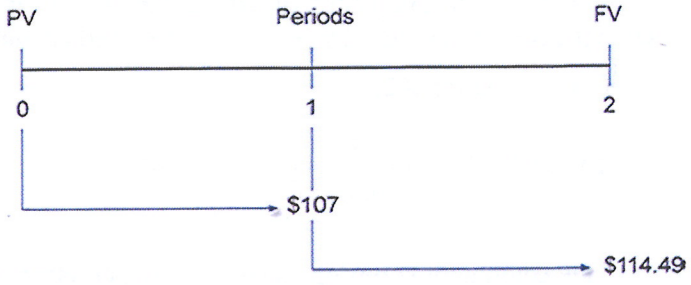

Figure 44

Future Value of a Single Payment

Note:

The interest rate "i" and the number of periods "N" must be in synch with each other. That is if "i" is an annual interest rate, then "N" must be the number of years or periods. Alternatively, if "i" is a monthly interest rate, then "N" must be the number of months as shown in the following example.

Example A2: Using the previous example (Example A1), suppose the interest rate quoted was 7 percent annual, compounded monthly rather than compounded annually as before. Calculate the future value at the end of five years.

The interest rate used would be (7% /12), and the exponent (N) would be ($N * 12$). Plugging these values into (Eq. A1) yields:

$$FV = \$500 * (1 + 0.07/12)^{5*12} = \$708.81$$

Notice the additional effect of monthly compounding when compared to annual compounding. An additional $7.53 accrued ($708.81 – 701.28) due to the more frequent compounding.

Present Value (Discounting)

To determine the present value (PV) of a future amount (FV), we simply rearrange Equation A1 and solve for (PV) as follows:

Equation A2

$$PV = FV * \left(\frac{1}{(1+i)^N} \right)$$

Where:

PV = Present Value
FV = Future Value
i = Interest or discount rate per period
N = Number of periods

Example A3: A building owner wants to put money in a bank account today to pay for a $5000 compressor overhaul that will be done in 5 years. How much should be deposit today in a savings account paying 6.5 percent, compounded annually?

Using Equation A2,

$$PV = \$5000 * \left(\frac{1}{(1+0.065)^5} \right) = \$3649.40$$

This amount must be deposited in today's dollars to grow to the desired future value.

This analysis is greatly simplified and ignores inflation, which erodes the future value each year. In other words, $5,000.00 today will not be worth $5,000.00 in five years. To be precise you should always use the nominal discount rate, which incorporates an assumed inflation rate, I.

Uniform Series Investments

The previous examples simplified the future value (FV) and present value (PV) as a single investment amount, however payments and costs are often incurred at different times over the life cycle period. These periodic or recurring investments are often made at regular intervals over the life cycle period. Periodic payments into an account add to the effect of compounding. When the same amount of money is paid, or received periodically it is referred to as a *uniform series*, also sometimes called an *annuity*. This text uses the term *uniform series* rather than the term *annuity* since the latter term is more appropriate for a particular type of investment instrument sold by insurance companies.

Uniform Compound Amounts (UCA)

To calculate the Future Value *(FV)* of a uniform series of investments, *A* made over time period *N*; the following formula may be used:

Equation A3

$$FV = A * \left[\frac{(1+i)^N - 1}{i} \right]$$

Where:

FV = Future Value
A = Annual payment
i = interest or discount rate per period
N = Number of periods

Example A4: A building owner put $500 per year in a bank account, which will be used to cover maintenance expenses 5-year in the future. The account pays 7 percent interest, compounded yearly. Calculate the future value (FV).

$$FV = \$500 * \left[\frac{(1+0.07)^5 - 1}{0.07} \right] = \$2875.37$$

As you can see, the additional $75.07 that accrued was compounded interest. As usual, it is easier to visualize these expenditures with a time line as shown in Figure 45:

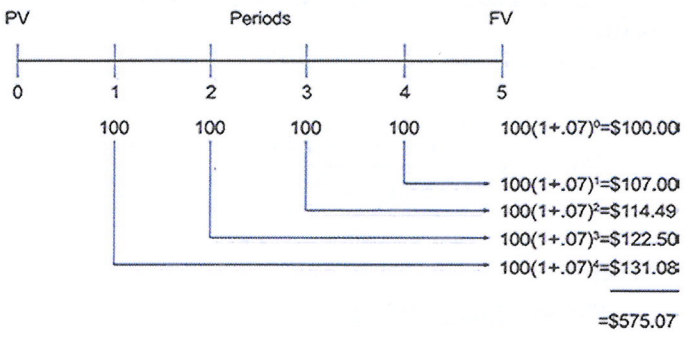

Figure 45

Uniform Compound Amount (UCA)

Uniform Sinking Fund (USF)

In cases where you know the desired amount of money that you want to accumulate at a future date (FV) you may solve for the annual investment amount, *A* required. This is referred to as a uniform sinking fund. This simply involves rearranging the UCA formula (Eq. A3) and solving for *A*, as follows:

Equation A4

$$A = FV * \left[\frac{i}{(1+i)^N - 1} \right]$$

Where:

A = Annual payment
FV = Future Value
i = interest or discount rate per period
N = Number of periods

Example A5: A building owner wishes to have $100,000 available for a unit replacement 15 years in the future; the bank interest rate is 5 percent compounded annually. How much should be put away each year?

$$A = \$100{,}000 * \left[\frac{0.05}{(1+0.05)^{15} - 1} \right] = \$4634.23$$

Uniform Present Value (UPV)

It is often more convenient to analyze costs at the beginning (PV) of the life cycle period rather than at the end (FV). Discounting all future values to their present value (PV) allows us to compare various design alternatives.

To calculate the present value of a uniform series, the *uniform series present value equation* is used:

Equation A5

$$PV = A * \left[\frac{(1+i)^N - 1}{i * (1+i)^N} \right]$$

Where:

PV = Present Value
A = Annual payment
i = interest or discount rate per period
N = Number of periods

Example A6: A high efficiency rooftop system will save $2,000 per year in energy costs. What is the life cycle present worth of these savings if the discount rate is 7 percent annually and the units expected life is 15 years?

$$PV = \$2{,}000 * \left[\frac{(1+0.07)^{15} - 1}{0.07 * (1+0.07)^{15}} \right] = \$18{,}215.83$$

It may be beneficial to look again at a time line as shown in Figure 46.

Notice the drastic effects of compounding interest in the later years, (years 13-15). The original $2,000 savings eroded to less than $725 by year 15. This demonstrates the powerful effects of compounding and the time value of money.

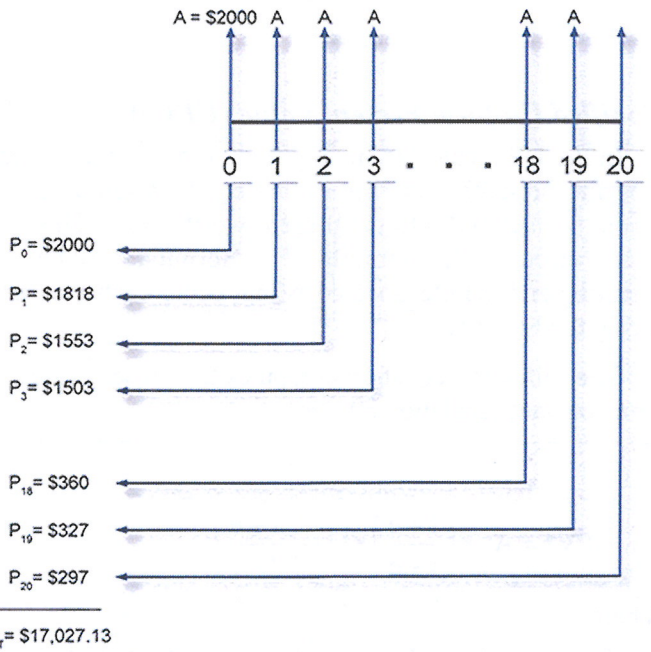

Figure 46

Uniform Series Present Value (UPV)

Uniform Capital Recovery (UCR)

A Uniform Capital Recovery calculation is used when you want to determine the periodic investment required to accumulate a certain quantity of money in present value (PV) terms. The UCR is simply Equation A5 rearranged to solve for the annual investment amount, *A* as follows:

Equation A6

$$A = PV * \left[\frac{i * (1+i)^N}{(1+i)^N - 1} \right]$$

Where:

A = Annual payment
PV = Present Value
i = interest or discount rate per period
N = Number of periods

Example A7: A split system unit with a present value of $15,000 will need to be replaced in 15 years. The owner wishes to make an annual payment into an account that has an interest rate of 4.5 percent so the system cost will be covered. What is the annual payment?

$$A = \$15{,}000 * \left[\frac{0.045 * (1 + 0.045)^{15}}{(1 + 0.045)^{15} - 1} \right] = \$1{,}396.71$$

Modified Uniform Present Value (UPV)*

In the UPV calculation (Eq. A5), above we assumed that the periodic payments, *A* remained constant throughout the life cycle period. When a constant cost escalation occurs each year this should be factored into the present worth value. This can be calculated using the Modified Uniform Present Value formula. This formula can be used to determine the present value for operating and maintenance costs that occur each year and are expected to increase at a fixed rate during the life cycle.

The following equation computes the present value (UPV*) of a periodic amount, accounting for a constant escalation rate, *e*:

Equation A7

$$UPV^* = A_1 * \left(\frac{1+e}{i-e} \right) * \left[1 - \left(\frac{1+e}{1+i} \right)^N \right]$$

Where:

A_1 = initial value of periodic payments at the beginning of the investment period
e = escalation rate per period (constant)
i = interest or discount rate
N = number of interest or discount periods

Example A8: A building owner is currently paying $20,000 annually for power. If the cost of electricity escalates at a 4 percent annual rate and the owner's discount (MARR) rate is 10 percent, what is the PV assuming *N*=20 years?

Substituting the known values into our equation:

$$UPV^* = \$20{,}000 * \left(\frac{1 + 0.04}{0.10 - 0.04} \right) * \left[1 - \left(\frac{1 + 0.04}{1 + 0.10} \right)^{20} \right] = \$233{,}759$$

Fuel prices are subject to price escalation that may not be adequately reflected by assuming a constant rate over the life cycle. This is particularly true when the life cycle is long. The United States federal government through the DOE (Department of Energy) annually issues a report of the anticipated energy price increases for the next 30 years. This report is known as the "Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis." The cost escalation data is given for each fuel type and for each region of the country in 5-year blocks. The UPV* equation above can be used for each 5-year block if the initial price for the block is determined.

Inflation

Inflation results in a decrease in the effective discount rate; it is a result of an overall increase in the cost of goods and services in the overall economy. Because inflation is a general increase it needs to be applied equally to all cost items in the analysis. If the discount rate used does not include the affects of inflation, the rate is called the *real discount rate* and if the impact of inflation is included, it is called the *nominal discount rate, r*. If the future amounts include the impact of inflation there are said to be in current dollars. If the impacts of inflation are not included they are said to be in constant dollars. The nominal discount rate, *i* and the real discount rate, *r* can be determined as follows:

Equation A8

$$r = \frac{(1+i)}{(1+I)} - 1 \quad \text{or} \quad i = (1+r)(1+I) - 1$$

Where:

I = general price inflation rate

r = nominal discount rate (current dollars)

i = real discount rate (constant dollars)

Example A9: To illustrate, suppose the real discount rate, i is 7.0 percent and the general price inflation rate, I is 3.0 percent, solving Eq. A8 above yields a nominal discount rate of 3.9 percent, or about 4.0 percent. For rough approximations, you can simply add or subtract the general rate of inflation, I to the appropriate discount rate used. Using either the real or the nominal discount rates will yield identical present values as long as you use consistent discount rates for all calculations.

$$r = \frac{(1+0.07)}{(1+0.03)} - 1 \; = 0.39 \text{ or} \approx 4\%$$

Escalation

Escalation is increases in the cost of a specific product or service that happens on an annual basis. The following two formulas can be used to determine the future cost of a service in a given year. The present value of a constant escalation rate with an annually reoccurring cost can be calculated using the UPV* formula presented above.

Constant Escalation Rate for each year:

Equation A9

$$FV = PV * (1+e)^n$$

Where:

FV = Future Value or cost

PV = Present Value or cost

e = escalation rate

N = Number of years

Example A10: The annual cost of a service contract for a building is $5,000 and it has been estimated it will escalates at a 4 percent annual rate. What is the cost of the contract in 10 years?

$$FV = \$5000 * (1 + 0.04)^{10} = \$7401.22$$

Variable Escalation Rate for each year:

Equation A10

$$FV = PV * \prod_{N=1}^{N=N} (1 + e)$$

Where:

FV = Future Value or cost

PV = Present Value or cost

e = escalation rate (constant dollars)

N = Number of years

Example A11: Electrical rates for a building are $8,000 annually. From "Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis" the escalation rates over the next five years are 3%, 2%, 4%, 3%, and 5%. What is the cost of electricity at the end of the fifth year?

$$FV = \$8000 * (1.03 * 1.02 * 1.04 * 1.03 * 1.05) = \$9453.38$$

The following table provides a summary of each of the formula:

Given:	PV	FV	PV	A	FV	A
To Find:	FV	PV	A	PV	A	FV
Factor Name	Single Compound Amount (SCA)	Single Present Value (SPV)	Uniform Capital Recovery (UCR)	Uniform Present Value (UPV)	Uniform Sinking Fund (USF)	Uniform Compound Amount (UCA)
Formula	$PV(1+i)^N$	$FV\frac{1}{(1+i)^N}$	$PV\frac{i(1+i)^N}{(1+i)^N-1}$	$A\frac{(1+i)^N-1}{i(1+i)^N}$	$FV\frac{i}{(1+i)^N-1}$	$A\frac{(1+i)^N-1}{i}$

Appendix B – Additional Resources

Carrier Hourly Analysis Program (HAP); Carrier Corporation, Syracuse, NY; 1-800-CARRIER; www.commercial.carrier.com

Carrier Engineering Economic Analysis Program; Carrier Corporation, Syracuse, NY; 1-800-CARRIER; www.commercial.carrier.com

Facilities Standard for the Public Buildings Service P100 (GSA) - Chapter 1.7 - Life Cycle Costing

Life-Cycle Cost Analysis (LCCA) - 10 CFR 436 Subpart A - Federal Energy Management and Planning Programs, Methodology and Procedures for Life-Cycle Cost Analyses

Means® Cost Data; R.S. Means Co. Inc.; Kingston, MA; 1-800-448-8182; www.rsmeans.com

References

ASTM Standards on Building Economics- 4th Edition; American Society for Testing and Materials; W. Conshohocken, PA; 1999

Engineering Economic Analysis User's Manual; Carrier Corporation, Syracuse, NY; 1992

HVAC Applications Handbook - 1999, ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.); Chapter 35; Atlanta, GA

Life-Cycle Costing Manual for the Federal Energy Management Program; NIST Handbook 135; 1995 Edition; Office of Applied Economics; Gaithersburg, MD; 1996

Glossary

Adjusted Internal Rate of Return (AIRR)	annual yield from a project over the life cycle period, taking into account investment of interim amounts
alternate case	a building or system alternative that is normally higher in first cost and lower in owning costs than the base case
annual cost method	a life cycle costing comparison method in which first costs and life cycle one time costs are converted into an equivalent cost over each year of the study
annually recurring cost	costs that occur each year at the same amount or increasing at a regular rate throughout the life cycle
base case	the system alternative or option to which the other alternatives will be compared; normally the alternative with the lowest first cost and the highest operating costs
base date	the beginning of the first year of the study, normally the starting date for the life cycle study
benefit-cost ratio	benefits divided by costs with both numbers discounted to their present worth values; generally a ratio greater than 1.0 is required to justify a particular investment
breakeven analysis	an economic analysis technique whereby the value of the benefit (savings) exactly offsets the cost
capital cost	the cost of acquiring, purchasing, replacing, modifying, or refurbishing a building component or system
cash flow	the stream of monetary values, (costs and benefits) resulting from a project investment
compounding	an economic analysis technique that calculates the growth in value of an initial investment amount, over time, based on an assumed interest rate and includes the effects of accrued interest
constant dollars	dollars, usually in terms of the first year of the study that exclude the impacts of inflation
current dollars	dollars, in terms of the year of the study that have lesser purchasing power because of inflation
demand charge	the portion of a utility bill based on usage during a time period, applies to commercial customers normally for electricity to help utility companies build generating and transmission facilities to meet peak conditions

discount rate (i)	a special type of interest rate used to determine the net present value (PV) of future cash flows; discount rate used reflects the investor's time-value-of-money or opportunity cost (see discounting); real discount rate (i) is an interest rate used to convert all future cash flows to present value (PV) terms, neglecting the effects of inflation; nominal discount rate (r) expresses values in current dollars taking inflation into account
discounted payback period	the time required for the savings accumulated from an investment to pay back the investment costs taking into account the time value of money
discounting	an economic analysis technique that converts cash flows, which may occur at different time periods in the future, to an equivalent amount at a common point in time (generally present day); also referred to as Present Value (PV); an assumed discount rate is used and generally corresponds to the minimum attractive rate of return (MARR) or other benchmark rate set by the analyst
energy costs	the annual cost of fuel or other energy sources to operate a building or system, this is amount as billed by the utility and includes usage costs, demand costs and fuel adjustments
escalation rate (e)	the projected annual rate of change of costs such as energy, labor, equipment and materials
future value	either a cost to be incurred in the future, or the values of a present cost at some future point in time
inflation (I)	the rise in the price of goods and services in the overall economy; generally caused by an imbalance in the supply and demand of a particular good or service, such that as demand increases while the supply remains constant or decreases, prices rise; opposite of inflation is deflation
initial investment cost	the costs of design, engineering services purchase and installation of a system, excluding any sunk costs, less residual value less any disposal costs
Internal Rate of Return (IRR)	the compound interest (discount) rate at which the present value of the future cash flows of a particular investment equals the cost of the investment.; determined by a trial-and-error procedure; when IRR > MARR, the investment is deemed acceptable
investment costs	expenditures made for assets such as first-cost of equipment, replacement cost of equipment, buildings or other items held by a company; these costs may be either financed or paid for with cash
Life Cycle Cost (LCC) Analysis	an economic technique used to compare various design alternatives by projecting (discounting or compounding) associated costs over the economic life of the project, (also called the "Life Cycle Period"), to a common period of time; all costs, which may occur at various times, are considered such as first cost, installation costs, maintenance costs and any additional expenditures such as replacement of components; bringing all of these costs, which occur at different times, to a common point in time, allows the analyst to compare various design alternatives and select the alternative with the lowest total cost

life cycle period	the time of consideration over which the economic analysis will be performed. often tied to the building owner's plans to retain ownership of the building or may correspond to the estimated useful life of the building or building systems.
Minimum Attractive Rate of Return (MARR)	the lowest acceptable rate of return on an investment as determined by the investor; capital budgeting decisions are typically made based on a fixed amount of available capital; determined by the building owner or cost analyst for any proposed capital expenditure; acceptable proposals meet or exceed the MARR
mutually exclusive projects	projects where the acceptance of one project alternative excludes the other alternatives.
Net Present Worth (NPW)	a method used to evaluate investment decisions whereby all future cash flows are discounted back to the beginning of the analysis period; the discount rate (i) used is the minimum attractive rate of return (MARR); if the NPW is positive, the proposal's forecasted return exceeds the MARR and the proposal is deemed acceptable
Net Savings (NS)	time adjusted savings of an alternative to the difference in investment costs over the base system
nominal discount rate	the rate of interest reflecting both the time vale off money and impacts of inflation
operating costs	costs incurred to operate equipment, which include energy, maintenance labor, insurance and taxes
planning and construction period	the period at the beginning of a project from the base date to the start of service date
present worth (pw)	the time equivalent value of past, present and future cash flows moved to the base year
real discount rate	the rate of interest reflecting the time value of money but not the impacts of inflation
replacement costs	capital costs incurred to replace a part of an alternative within the study period, but not an annually recurring cost.
residual value	the estimated value less any disposal costs for a system alternative
Return on Investment (ROI)	an economic analysis technique that determines the financial gain associated with an investment of capital; calculated by dividing the net annual cash flow by the investment amount, expressed in percentage terms; should be used as a relative comparison against alternative investments, such as government bonds or other investments, to make financial decisions; also equivalent to the reciprocal of the simple payback period
salvage value	the residual value of an asset, assigned for tax purposes, which is expected to exist at the end of the depreciation period; see also residual value

Savings-to-Investment (SIR) Ratio	equal to either the ratio of present value savings to present value investment costs or the ratio of annual savings to annual investments and is often used by municipalities or U.S. government agencies; must be greater than 1.0 to justify the investment
sensitivity analysis	testing the outcomes of an economic analysis to determine the impact of changes to one or more of the cost parameters
service date	the point in the study where the system is put into operation and when savings begin
Simple Payback (SPB)	an economic analysis technique that indicates the number of periods (usually years) necessary to recover an investment of capital, without consideration to the time value of money; calculated by dividing the investment amount by the net annual cash flow amount; generally, a simple payback period of 3-5 years or less is desirable as it translates to an ROI value of between 20-33%; SPB may also be calculated by taking the reciprocal of the ROI
simple payback period	the time necessary for the cumulative benefits (savings) from an investment to offset or equalize the investment cost, with no consideration of the time value of money.
study period	the length of time covered by the study
sunk costs	costs that have been incurred and cannot be changed. These costs should not be considered in the study
time value of money	the time dependent value of money reflecting the opportunity cost to the investor.
time-of use rates	utility rate structures which vary from time period to time period, these changes may be daily or seasonal
Value Engineering (VE)	a systematic evaluation technique of evaluating option by option and subsystem by subsystem the overall benefit achieved by the option or subsystem compared to the cost. Options with inadequate return on investment are eliminated if the impacts on other system requirements, IE comfort, are not compromised.

Prerequisites:

To obtain the highest benefit from this module, it is suggested that participants have prerequisite knowledge from the TDPs listed below, or equivalent.

TDP No.	Book Cat. No.	Instructor CD Cat. No.	Title
TDP-103	796-027	797-027	Concepts of Air Conditioning

Learning Objectives:

After reading this module, participants will be able to:

- Understand why Life Cycle Cost studies are required
- Explain and use the Life Cycle Cost analysis procedure
- Calculate Simple Pay Back and Return on Investment
- Describe the Time value of money and income vs. cost analysis
- Calculate Present and future value for single or series payment
- Explain how Public vs. private analysis differ
- Explain the five analysis methods for decision-making
- Selecting the appropriate methods required for decision making in each of the five economic decision
- Explain the impacts of Depreciation and taxes and non-economic impacts
- Perform a Life Cycle cost analysis using a LCCA analysis program

Supplemental Material:

None

Instructor Information

Each TDP topic is supported with a number of different items to meet the specific needs of the user. Instructor materials consist of a CD-ROM disk that includes a PowerPoint™ presentation with convenient links to all required support materials required for the topic. This always includes: slides, presenter notes, text file including work sessions and work session solutions, quiz and quiz answers. Depending upon the topic, the instructor CD may also include sound, video, spreadsheets, forms, or other material required to present a complete class. Self-study or student material consists of a text including work sessions and work session answers, and may also include forms, worksheets, calculators, etc.



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