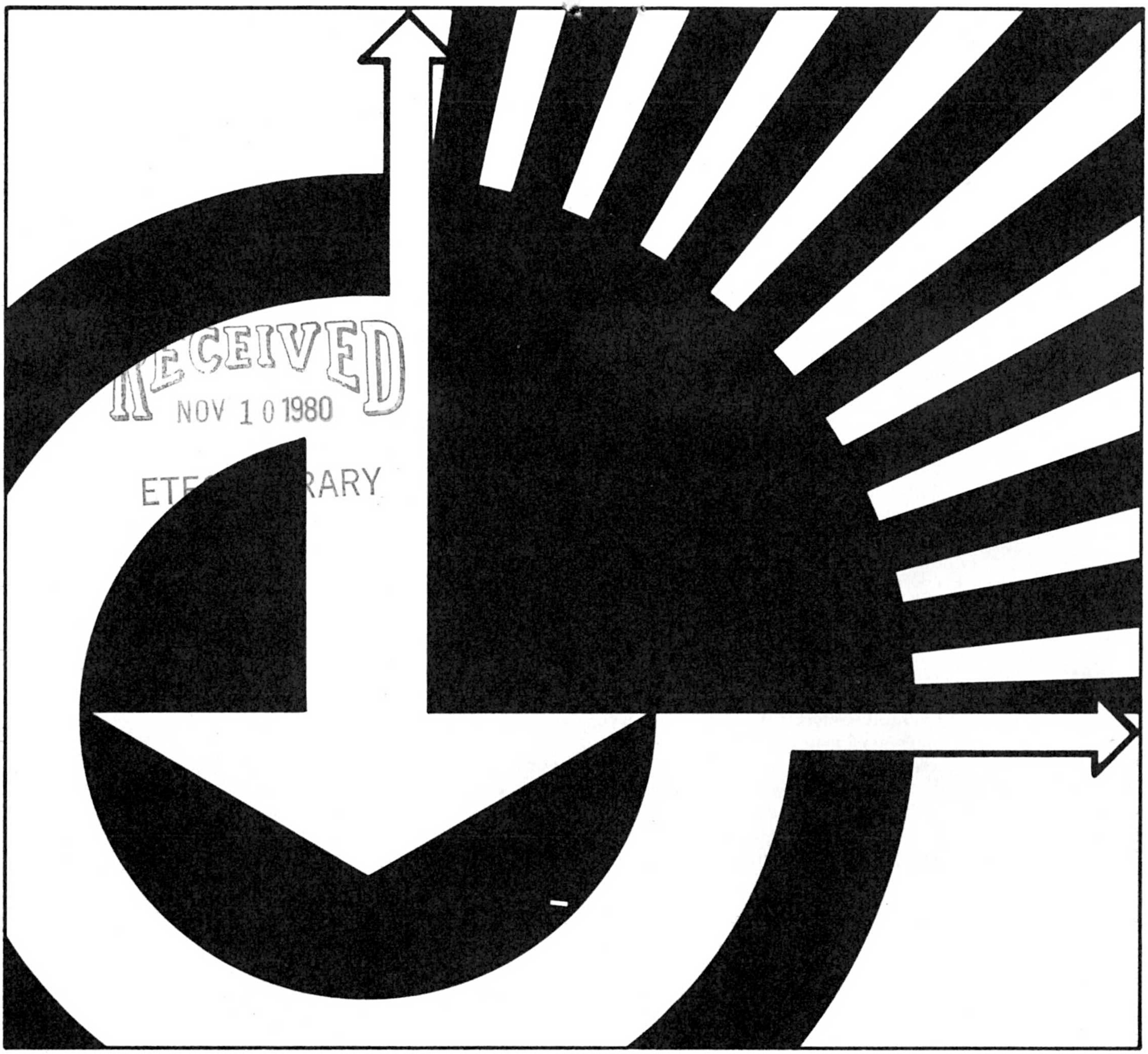

NBS Handbook 132

Energy Conservation in Buildings: An Economics Guidebook for Investment Decisions

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

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Energy Conservation in Buildings: An Economics Guidebook for Investment Decisions

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PREFACE

This guidebook was prepared by the Applied Economics Group in response to a need expressed by the building design community for assistance in evaluating the economics of energy conservation investments in buildings. The authors thank Stephen Weber, Robert Hastings, Bobbie Cassard, and George Turner of the Center for Building Technology, and Maureen Breitenberg of the Office of Engineering Standards for constructive reviews of this report. Appreciation is due Cindy Broussalian, who provided creative designs for the cover and first pages of each section, to Steve Roberts, who assisted with the problems section, and to Mary Ramsburg and Laurene Linsenmayer, who typed the manuscript. Special thanks are also due the class members of a short course, "Design Economics for Energy Conservation in Buildings," taught as a test case by staff from the Applied Economics Group for the University Extension Program of the University of California at Berkeley. Class members, most of whom were practicing architects, wrote evaluations of the course content. These evaluations were used in the development of an outline for the guidebook responsive to the needs of the design community.

Simplified Energy Design Economics: Principles of Economics Applied to Energy Conservation and Solar Energy Investments in Buildings, a more simplified version of this report, was published by the National Bureau of Standards in January 1980. The simplified report was prepared as an introductory primer on design economics for practicing architects and designers and for students of these disciplines, with special editing and illustrations by architect Forrest Wilson. This guidebook is a more comprehensive and complex treatment of the same subject, with detailed illustrations and extensive problem sets of varying difficulty. The guidebook complements the simplified design report by providing additional information that assists the architect/designer in solving more complicated design problems. It also provides analysts outside of the design profession with tools to evaluate energy conservation investment problems.

ABSTRACT

Energy conservation in buildings has become critical in the planning and design of buildings due to increasing energy prices and the threat of fuel shortages. Architects, engineers, builders, and others concerned with the design and operation of buildings need principles and guidelines for making economically efficient investment decisions in energy conservation. This guidebook provides principles, techniques, step-by-step illustrations, and sample problems on how to evaluate the economics of energy conservation and solar energy investments. Techniques of economic evaluation including life-cycle costing, net benefits, savings-to-investment ratio, internal rate-of-return, and discounted payback analyses are described and compared in terms of their advantages and disadvantages. Discounting, a procedure for taking into account the time value of money, is illustrated in the analysis of an investment in heat pumps. Practice problems for discounting and for applying each of the five techniques are presented. Factors that affect benefits and costs, including time horizons, discount rates, inflation, incentives, taxes, salvage values, and measures of uncertainty, are discussed, and guidance is provided for selecting appropriate values for these factors when making economic evaluations. Comprehensive case illustrations for solar heating and for window design management are described. Appendices provide tables and formulas for evaluating the economics of alternative conservation investments.

Key words: Benefit cost; building economics; discounting; economic analysis; economic efficiency; energy conservation; incentives; life-cycle cost; payback; rate of return; solor economics; windows.

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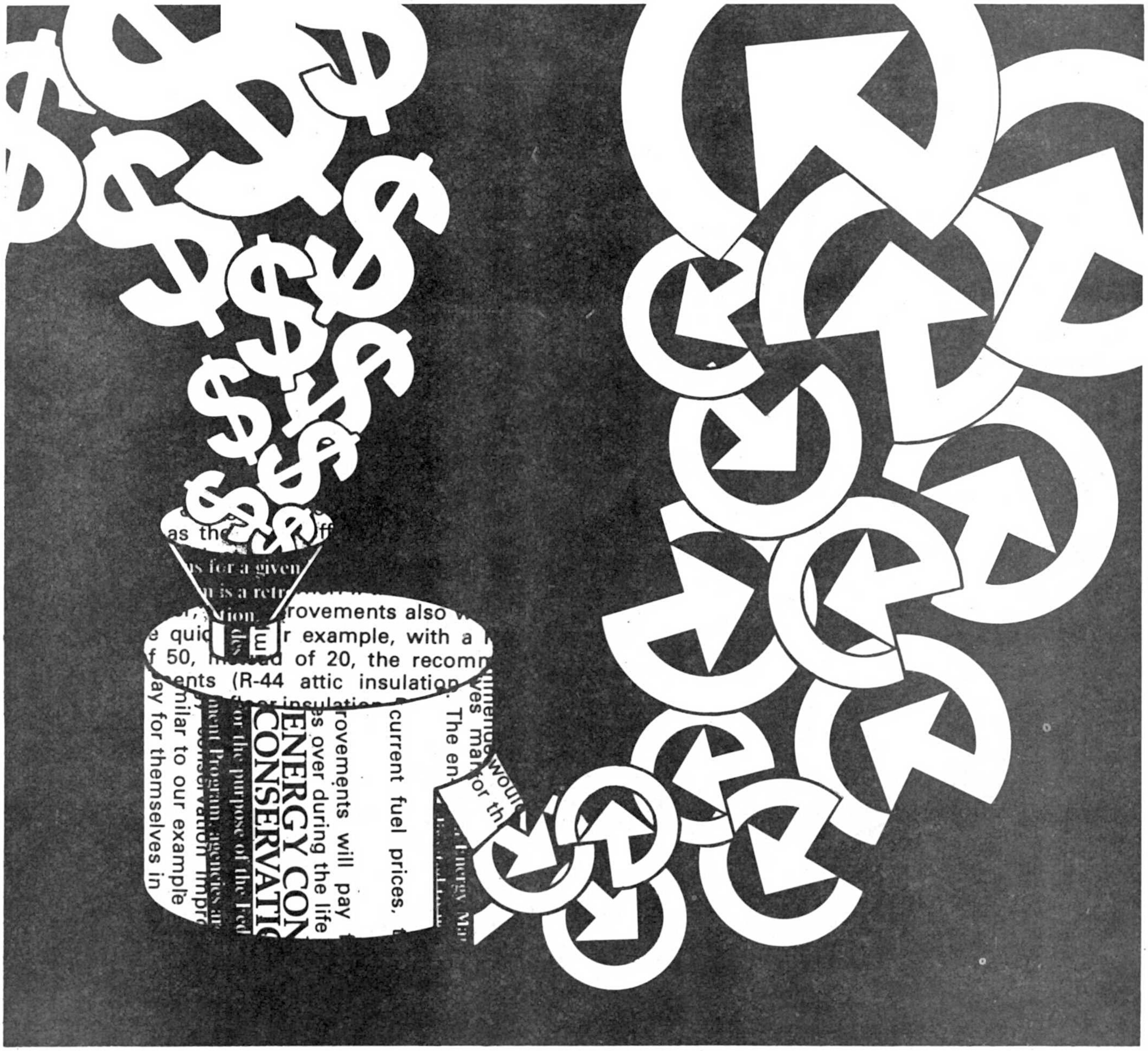

1. Introduction

1.1 BACKGROUND

Energy conservation is being given increasing attention in the planning and design of building shells and equipment as energy prices continue their rapid rise and fuel shortages threaten. The rise in prices reflects the natural and contrived scarcity of fuels, the increased cost of energy production and delivery resulting from government regulations to reduce water and air pollution, and increased demands by an energy-intensive society. The statistics in table 1.1 show how United States energy consumption for buildings, both in terms of physical quantity and dollar expenditures, has changed from 1950 to 1976. It also shows how the unit price of that energy has changed from year to year. Energy consumption (column 2) increased over 134 percent during the 26 year period. Energy consumption measured in 1977 dollars (column 3) rose every year, with a cumulative increase of approximately 233 percent over the 26 years. The unit price of energy (column 4) varied during the years 1950 to 1970, but increased by approximately 44 percent over the entire period through 1976. In fact, as shown by the negative percentage changes in column 5, the price of energy declined in almost half the years.

A look at the statistics shows clearly why energy conservation has become critical to the design community. From 1970 through 1976, the price of energy rose 39 percent, a large part of the total rise of 44 percent over the entire 26 year period. And even though energy consumption actually fell two years during the 1970-1976 period, dollar consumption increased by over 28 billion dollars, a 54 percent increase.

The Federal government is concerned with reducing expenditures for energy in private and public buildings both to meet critical national needs in all areas of energy use and to mitigate the negative effects of energy fuel imports. Federal programs to reduce energy consumption of depletable energy sources range from research and development in renewable energy sources like solar energy to legislation that encourages or mandates energy conservation in the public and private sectors. State and local governments faced with stringent budgets are also concerned with energy conservation in their buildings. In the private sector, businesses and consumers are seeking ways to reduce their utility bills by investing in energy conservation.

Building owners, architects, mechanical engineers, builders and others concerned with the design and operation of buildings are currently under pressure from government bodies[1] as well as from private sector clients and consumers to plan more energy efficient buildings. At the same time, there is considerable concern about the overall costs of buildings. A large part of the demand for energy conservation involves lowering the total ownership and operating costs of buildings by achieving a savings in energy costs that more than outweighs the costs of the conservation. Selecting investments in energy conservation that both reduce energy consumption and lower total life time building costs is facilitated by the use of economic analysis. Principles and guidelines for making economically efficient investment decisions in energy conservation are needed by all sectors of the building community.

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[1] See, for example, State of California, Energy Resources Conservation and Development Commission, Conservation Division, Energy Conservation Design Manual for New Nonresidential Buildings, October 1977, a document that describes the requirements for energy conservation that must be met prior to the application for a nonresidential building permit in California.

TABLE 1.1 ANNUAL ENERGY CONSUMPTION FOR SPACE HEATING AND COOLING IN RESIDENTIAL AND COMMERCIAL BUILDINGS IN THE UNITED STATES 1950-1976

YEAR	CONSUMPTION 10^{12} Btu[a]	(10^6 GJ)	CONSUMPTION 10^9 1977 $[b]	PRICE PER 10^6 BTU 1977 $[c]	PERCENTAGE CHANGE IN PRICE PER 10^6 BTU
(1)	(2)		(3)	(4)	(5)
1950	8,139	(8 587)	24.4	3.00	N.A.[d]
1951	8,472	(8 938)	24.8	2.93	-2.3
1952	8,645	(9 121)	26.0	2.99	2.0
1953	8,490	(8 957)	27.1	3.18	6.4
1954	8,765	(9 248)	28.7	3.27	2.8
1955	9,449	(9 969)	30.8	3.26	-0.3
1956	9,898	(10 443)	33.0	3.37	3.4
1957	9,704	(10 238)	34.3	3.49	3.6
1958	10,562	(11 144)	34.8	3.29	-5.7
1959	10,914	(11 515)	36.7	3.37	2.4
1960	11,436	(12 066)	37.8	3.29	-2.4
1961	11,758	(12 405)	39.8	3.37	2.4
1962	12,438	(13 123)	41.6	3.34	-0.9
1963	12,661	(13 358)	43.1	3.40	1.8
1964	12,935	(13 647)	43.6	3.38	-0.6
1965	13,778	(14 537)	45.8	3.31	-2.1
1966	14,489	(15 287)	47.2	3.26	-1.5
1967	15,271	(16 112)	49.0	3.22	-1.2
1968	15,576	(16 434)	49.2	3.16	-1.9
1969	16,358	(17 259)	50.9	3.12	-1.3
1970	16,988	(17 923)	52.8	3.10	-0.6
1971	17,421	(18 380)	55.6	3.19	2.9
1972	18,066	(19 061)	59.2	3.28	2.8
1973	18,012	(19 004)	61.7	3.43	4.6
1974	17,616	(18 586)	69.2	3.93	14.6
1975	17,670	(18 643)	74.3	4.21	7.1
1976	19,079	(20 129)	81.2	4.31	2.4

[a] G.E. Liepins et al., Buildings' Energy Facts and Trends (Draft in Preparation), Oak Ridge National Laboratory, Oak Ridge, Tennessee, November 1977, pp. 7-10. Data for 1976 were obtained by interview from Mr. Charles Reading, U.S. Department of the Interior.

[b] Calculated by multiplying the annual energy consumption by the appropriate fuel price. Prices for natural gas, electricity, and fuel oil were taken from Buildings' Energy Facts and Trends (Draft). Recent coal prices were calculated by extrapolation using the Anthracite Coal (stove size) historical price index taken from Historic Statistics of the United States, U.S. Department of Commerce, September 1975.

[c] Prices reflect a weighted average of the four energy sources (gas, electricity, petroleum and coal) converted from current year dollars to 1977 dollars by the Implicit Price Deflator for Personal Consumption Expenditures, taken from Survey of Current Business, U.S. Department of Commerce, July 1977, Table 8.8.

[d] Not applicable.

While traditional microeconomic theory and engineering economics courses have long offered instruction in the general principles of economic evaluation, little published material and few courses have been available to meet the specific demands for economic guidelines applied to energy conservation investments in buildings.

1.2 PURPOSE AND SCOPE

The purpose of this guidebook is to provide principles, techniques, step-by-step illustrations, and sample problems that will be helpful in determining if it is economically efficient to invest in specific energy conservation and solar energy projects. Although the guidebook should be useful to students of the design profession, it is aimed primarily at practicing professionals who currently make decisions about energy conservation in old and new buildings. This group includes architects, mechanical engineers, designers, builders, codes and standards writers, and government policy makers, collectively referred to hereafter as the design community.

The focus of the guidebook is on the analyses required for making economically efficient choices among alternative energy conservation and solar investments. Standardized approaches are provided that will be useful for a variety of investment decisions. The emphasis is on practical methods of problem solving rather than on theoretical discussions. The mathematical derivation of formulas, for example, is left to the traditional textbooks in economic theory and engineering economics.

1.3 APPROACH AND ORGANIZATION

The approach is, first, to explain briefly the basic principles of economics required for understanding and performing economic evaluations of alternative investment decisions; second, to present realistic case illustrations of economic evaluations of energy conservation and solar energy investments; and, third, to provide sample problems for self-instruction.

Section 2 explains the concept of economic efficiency, discusses the measurement of benefits and costs, and provides a general description of five commonly used techniques of economic analysis: life-cycle cost analysis, net benefits analysis, the savings-to-investment ratio method, the internal rate-of-return method, and discounted payback analysis. Simple problems are presented with each technique. The advantages and disadvantages of each technique are discussed. Suggestions are made for selecting the appropriate technique for treating specific types of investment problems in energy conservation.

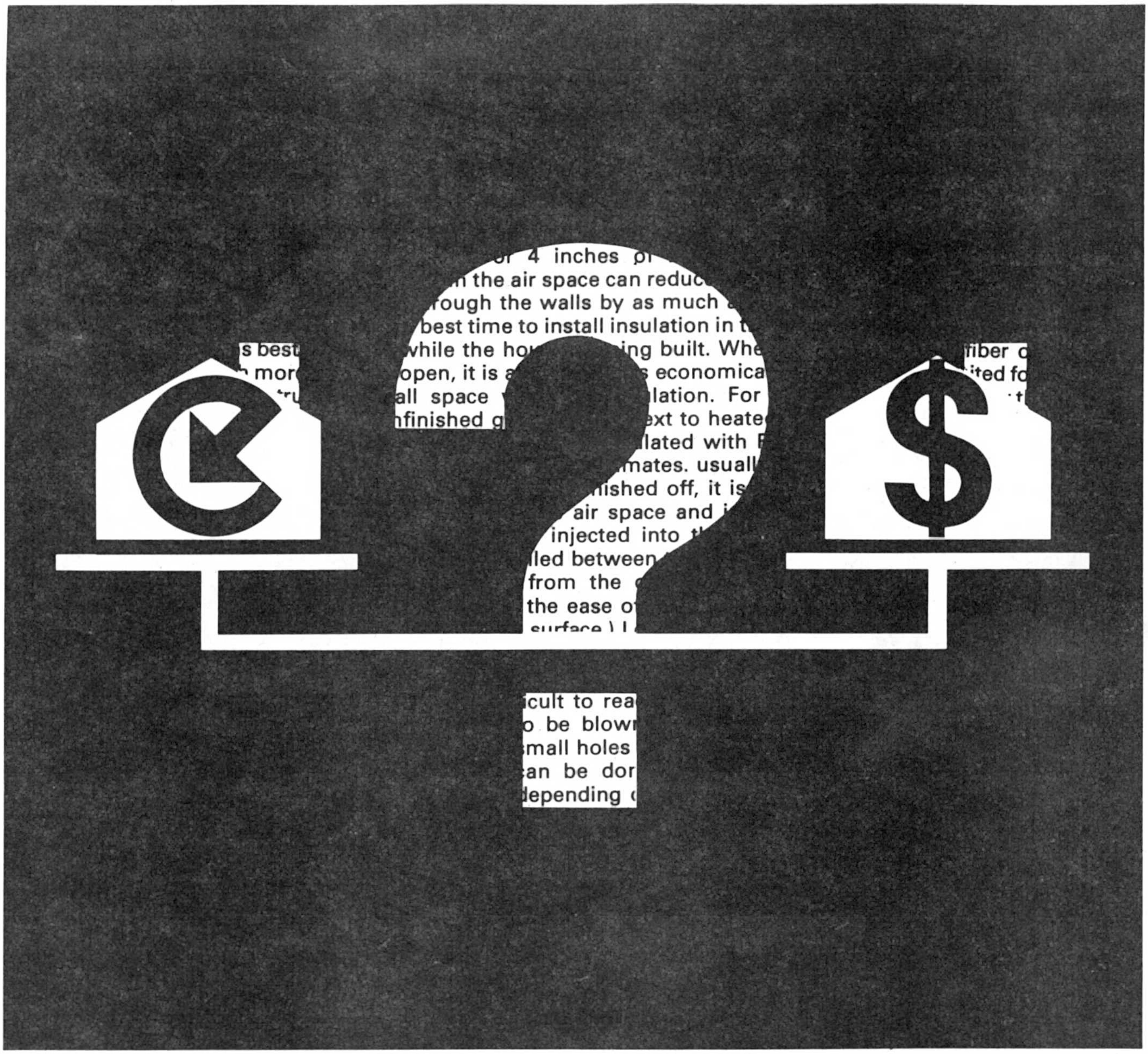
Discounting, a procedure for converting cash flows to a time equivalent basis, is described in section 3. A problem on the economics of heat pumps illustrates the various discounting procedures.

The factors that significantly affect benefits and costs are identified and discussed in section 4. Guidance is provided for selecting appropriate values of these factors for making economic evaluations. The implication of selecting inappropriate values are also discussed. Time horizons, discount rates, inflation, incentives, taxes, salvage values, and measures of uncertainty are included.

Sections 5 and 6 provide comprehensive illustrations of the application of the principles described in the preceding sections to solar heating and window design and management. For each of the two case studies, the objective is described, investments are identified, and an appropriate technique of economic analysis is applied to select the most economically efficient option. The solutions to the case problems and their implications are described.

Section 7 constitutes material for self-instruction. Fifteen problems in energy conservation and solar energy are presented in increasing order of difficulty. Following each is a step-by-step solution. Working through these problems will help prepare the reader to carry out economic evaluations of energy conservation and solar energy investments. These problems require use of the discounting procedure described in section 3 and of the five techniques of analysis described in section 2.

A glossary of economic terms, discount formulas, and discount factors conclude the report in a series of appendices.



2. Techniques of Economic Analysis

Economic analysis can be used in a number of ways to increase the economic efficiency[1] of investments in energy conservation. It can be used to obtain the largest possible reductions in energy costs for a given energy budget. It can be used to achieve a targeted

---

[1] Note that economic efficiency is <u>not</u> necessarily the same as engineering efficiency. For example, one furnace may be more "efficient" than another in the sense that it delivers more units of heat for a given quantity of fuel than another. Yet it may not be economically efficient if the first cost of the higher-output furnace outweighs its savings in reduced fuel consumption. The focus in this paper is on economic efficiency, the maximizing of benefits net of costs, or the minimizing of the costs of achieving a given level and quality of output.

reduction in energy costs for the lowest possible conservation investment. And, more broadly, it can be used to determine how much it pays to spend on energy conservation in order to lower total life time building costs, including investment, energy, and non-fuel operation and maintenance costs.

The first two ways of using economic analysis, i.e., to obtain the largest savings for a fixed budget and to obtain a targeted savings for the lowest budget, are more limited applications of economic analysis than the third use which aims at minimizing the total building costs or, in other words, at maximizing the net benefits from energy conservation. As an example of the first application, building owners may budget a specific sum of money for the purpose of retrofitting their buildings for energy conservation, from which they wish the largest possible return. As an example of the second, designers may be required by State or Federal building standards or codes to reduce the design energy loads of new buildings to some specified level, and, to stay within their budgets, they seek to reach the targeted level by using the most cost-effective methods of energy conservation. As an example of the third application, designers or builders may be requested by their clients to include in their buildings those energy conservation features that will pay off in terms of lower building costs.

In this section, the fundamental principles of using economic analysis to make economically efficient investments in energy conservation are described graphically. The measurement of the costs and benefits associated with energy conservation are discussed briefly. Five different techniques for combining costs and benefits for use in evaluating investment decisions are presented and compared for application to common types of conservation investment decisions.

2.1 CONCEPTS OF ECONOMIC EFFICIENCY

Achieving economic efficiency in energy conservation has two dimensions: (1) determining the most profitable <u>level</u> of energy conservation, and (2) determining the most profitable <u>combination</u> of energy conservation techniques for a given investment budget. These two dimensions are actually inseparable, in that the overall level of conservation which is most economically efficient depends on the costs and savings of available energy conservation techniques, and the most profitable combination of conservation techniques requires that the appropriate level of each technique is determined based on its relative costs and savings.

If there were no budget limitation, it would pay to continue to invest in each available technique as long as the additional, or "marginal," savings exceeded the additional, or "marginal," cost. Thus the level of the <u>total</u> conservation investment would increase as long as marginal savings from the entire "package" of conservation techniques exceeded the marginal costs.

Figures 2.1 and 2.2 illustrate the economic conditions that must be met for the efficient level of investment to be achieved either for an individual energy conservation technique or for a total package of energy conservation techniques when budget limitations do not apply.

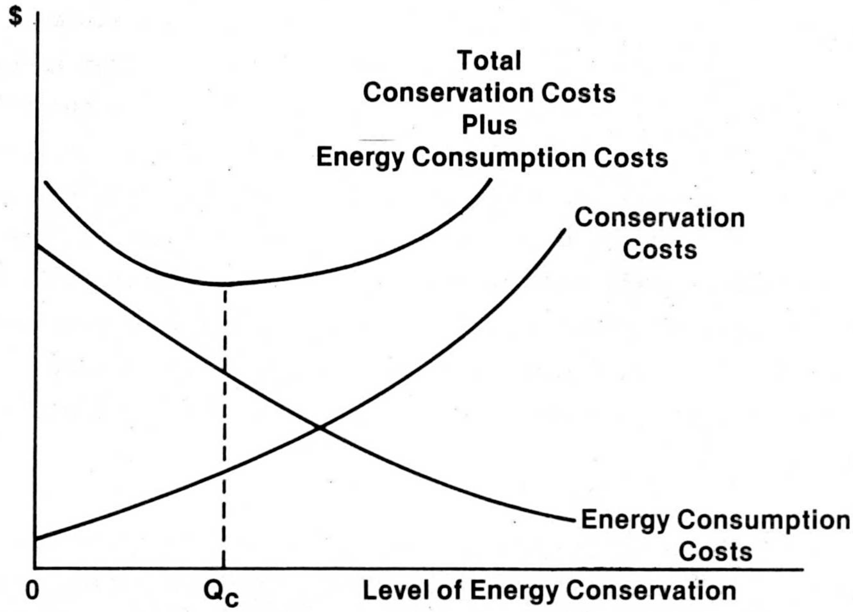


FIGURE 2.1 Level of Energy Conservation (Q_C) that Minimizes Total Energy-Related Costs.

Figure 2.1 shows an economic tradeoff between energy conservation costs (the upward sloping line from left to right) and energy consumption costs (the downward sloping line from left to right). It shows that conservation costs are at first more than offset by the fall in energy costs, but eventually, as more conservation is undertaken, the rise in conservation costs becomes greater than the fall in energy costs. This is reflected in the total cost curve (the upper "U"-shaped curve), which falls to a minimum point and then rises. The most economically efficient level of energy conservation is that for which the total cost curve is at a minimum, as indicated in figure 2.1 by "Q_c".

Another way of describing this concept is in terms of maximizing the net benefits from energy conservation. Figure 2.2 illustrates in two graphs the concept of maximizing the net benefits from energy conservation. Using this concept, the reduction in energy costs are the benefits, and the objective is to find the level of energy conservation for which the difference between the costs and the benefits of conservation is greatest.

The top graph in figure 2.2 shows that total costs of conservation tend to rise slowly at first, but then begin to rise more sharply as more and more conservation is undertaken, such that the cost curve typically bends upward. Total benefits (energy savings), on the other hand, tend to rise more slowly as more and more conservation is added to a building, such that the benefits curve typically rises at a decreasing rate. As long as the benefits curve lies above the costs curve, the energy conservation is profitable. The point at which the curves are most distant, with benefits above costs, indicates the level of conservation that is most profitable. The point at which the curves intersect indicates a break-even level of energy conservation, i.e., a level for which benefits are fully offset by costs. The cost curve rising above the benefits curve indicates that the energy conservation investment loses money.

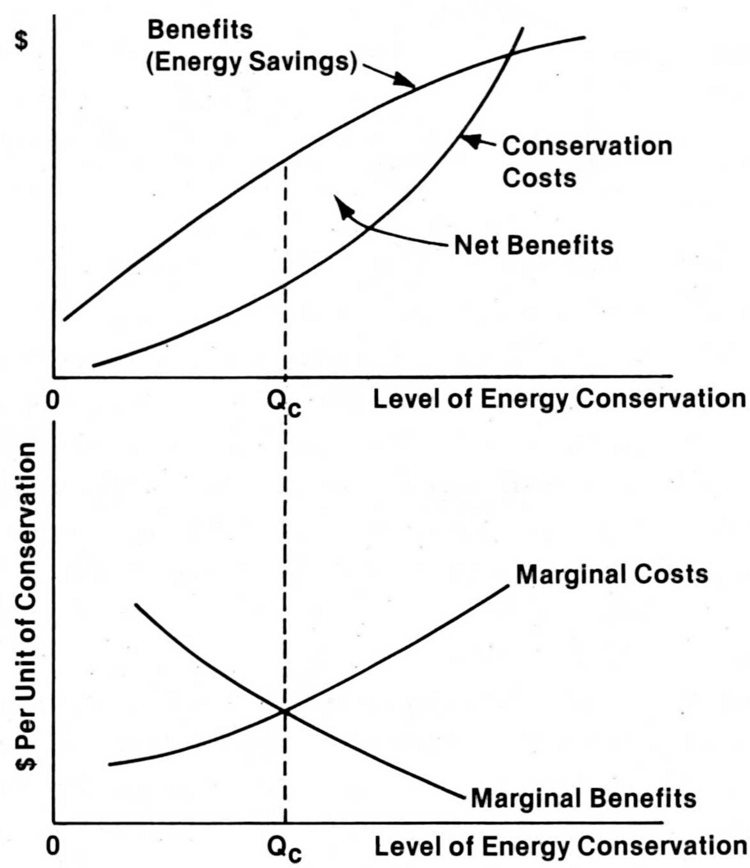


FIGURE 2.2 Level of Energy Conservation (Q_C) that Maximizes Net Benefits.

The lower graph shows how "marginal analysis" can be used to find that level of conservation that will yield the largest net benefits. The lower graph depicts the changes in the total benefits and cost curves of the top graph, as the level of energy conservation is increased. The point of intersection of these curves coincides with the most profitable level of energy conservation indicated on the top graph. This is the point at which the cost of adding one more unit of conservation is just equal to the corresponding benefits in terms of energy savings (i.e., the point at which "marginal costs" and "marginal benefits" are equal and the ratio of marginal benefits to marginal costs is equal to one). To the left of the point of intersection, the additional benefits from increasing the level of conservation by another unit are greater than the additional costs, and it pays to invest more. To the right of the point of intersection, the costs of an addition to the level of conservation exceed its benefits and the level of total net benefits begins to fall, as shown by the top graph. The most economically efficient level of conservation is indicated on both figures 2.1 and 2.2 as Q_c. Level Q_c, the level at which the ratio of marginal benefits to marginal costs equals one, is the economically efficient level of investment for any given energy conservation technique as well as for the total package of techniques.

If, however, budget limitations prohibit undertaking all energy conservative techniques up to level Q_c in figures 2.1 and 2.2, the "fall-back" approach is to allocate the limited budget among available techniques, stopping short of the "Q_c" level, so as to maximize net savings for that budget.

The most profitable combination of techniques for a limited budget is that in which each technique is used to the level that its ratio of marginal savings to marginal costs is equal to the ratio for all other techniques. However, instead of the ratio being one at the margin, the level of investment will by necessity stop when the ratio is greater than one. If the ratio were higher for one technique than another, it would pay to shift investment from the technique with the lower ratio to the one with the higher ratio in order to raise total net savings.

2.2 MEASURING BENEFITS AND COSTS

To evaluate the economic attractiveness of an investment, it is necessary to measure the benefits and costs associated with the investment. In broad terms, benefits from a conservation investment include both the monetary value of the resulting energy savings and the non-monetary value of other beneficial effects of the investment. "Non-monetary" means that it is difficult to place a dollar value on benefits. It does not mean that the benefit has no value. There may be non-monetary benefits that are enjoyed directly by the person or organization who invests in energy conservation, as well as non-monetary benefits that extend beyond the investor.

An example of an investment in conservation that may have non-monetary benefits is the planting of deciduous trees. The trees might have aesthetic value beyond their energy savings from blocking the summer sun and allowing the winter sun to warm the building. Another example is caulking and weatherstripping around windows and doors--an action that might improve comfort in addition to saving energy.

An example of a non-monetary benefit that may extend beyond the investor is the lack of air pollution by solar energy systems. Examples of non-monetary benefits from energy conservation that extend to the national level are a strengthening of national security and an improvement in the balance of trade due to reduced reliance on imported oil.[1]

Although both monetary and non-monetary benefits are important, the focus of this report is on monetary benefits for two major reasons: (1) the state of the art of measuring benefits makes it difficult to treat the non-monetary values in a meaningful way; and (2) many investors make their investment decisions primarily on the basis of direct monetary benefits to them.[2]

Costs are the total monetary and non-monetary burdens that result from a conservation investment. Examples of monetary burdens are the first costs and the maintenance and repair costs that are incurred in providing a conservation feature to a building. An example of a non-monetary cost that might result from energy conservation is a less attractive building facade. As with benefits, the focus of this report is on those costs that can be measured in dollars with a reasonable degree of confidence.

Reductions in energy costs through conservation can be treated as benefits with the objective being the maximization of net benefits. Alternatively, they can be treated as negative costs with the objective being to minimize total life-cycle costs.

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[1] In recognition of these societal benefits that extend beyond the private investor, the government sometimes provides subsidies to encourage greater investment in goods or services that have high societal benefits, or penalties to discourage investments that have some high societal costs.

[2] It is recognized that investors can be strongly influenced by factors not directly translatable into monetary terms, such as the desire for energy independence, the appeal of being in the forefront of a national cause or in using new technology, as well as by altruism. Again, however, these non-monetary forces are difficult to predict or to quantify.

Information needed to prepare life time benefit and cost estimates include energy quantity and price data;[1] projections of energy price escalation; operation, maintenance, and repair costs; and present and future investment costs. Frequency of replacement, tax rates, cost of money, and government incentive programs are additional factors that must be known.[2] How this information can be used to evaluate alternative conservation investments will be demonstrated in the case applications.

2.3 TECHNIQUES

Five techniques of economic evaluation that may be useful in evaluating energy conservation investments are (1) total life-cycle cost analysis (TLCC), (2) net benefit (savings) analysis (B-C), (3) the savings-to-investment (SIR) or benefit-cost (B/C) ratio method, (4) the internal rate of return method (IRR), and (5) the discounted payback method (DPB).[3] All of these techniques take into account the timing of cash flows and the associated costs of money, and all, except the discounted payback method, evaluate benefits and costs over the life cycle. The first four techniques listed are, in other words, comprehensive techniques of economic analysis that can be used to evaluate investments in energy conservation, taking into account their frequently high first costs and their savings spread out in the future and changing in amount over time. The fifth technique, the discounted payback period method, is included even though it does not take a comprehensive life-cycle approach. This technique is included because designers sometimes have clients who require a rapid turnover of their investment fund and may request the use of a payback technique.

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[1] For guidance in planning, calculating, and documenting the energy analysis of a building, see, for example, Reynolds, Smith, and Hills, Architects-Engineers, Planners, Life-Cycle Costing Emphasizing Energy Conservation: Guidelines for Investment Analysis. Energy Research Development Administration Manual 76/130, Revised May, 1977; and Public Technology, Incorporated, Energy Conservation Retrofit for Existing Public and Institutional Facilities. Prepared for the National Science Foundation (RANN), Washington, D.C., 1977.

[2] Informational references for these other factors are given later in the paper.

[3] There are other methods that are often used by businesses to evaluate investment alternatives. These include the return on investment method (ROI), the return on average investment method (R.O.A.I.), and the simple payback (SPB). These methods are essentially accounting approaches to measuring investment worth. While they are sometimes favored by management as methods that provide a quick and easy initial review of an investment, they have the major weaknesses of (a) not taking into account the timing of cash flows and the related cost of money and (b) failing to evaluate the total lifetime benefits by focusing on average yearly values. These are not included in the list of techniques above, because an objective of this report is to provide a guide to the more reliable methods of economic evaluation.

Each of these five techniques is defined below, both verbally and in abbreviated algebraic form. Following the definitions, the advantages and disadvantages of each technique are discussed, and recommendations are given for the appropriate uses of each technique.

Inclusion of the cost of money through a process called discounting is a feature of each of the five techniques. This process is described in section 3. In the following descriptions of techniques, for simplicity, the algebraic discounting expressions are not shown explicitly. Similarly, the detailed algebraic expressions required to account for tax effects and incentives are not shown. The emphasis here is distinguishing among the five techniques in their particular method of relating benefits and costs to derive a measure of the economic attractiveness of an investment.

2.3.1 Total Life-Cycle Cost Analysis (TLCC)

The analysis of total life-cycle costs calls for summing the net costs of acquisition, maintenance, repair, replacement, energy, and any other monetary costs attributable to the conservation investment, including the cost of money, over the life of the investment. All costs are usually measured either in present value or annual value dollars.[1] The investment that has the lowest total life-cycle cost while meeting the investor's objectives and constraints is the preferred investment.

Following is a general formula for finding the total life-cycle costs of an investment in energy conservation:

$$\underbrace{TLCC}_{\text{Total Life-Cycle Costs (dollars)}} = \underbrace{P}_{\text{Purchase and Installation Costs}} - \underbrace{S}_{\text{Salvage Value}} + \underbrace{M}_{\text{Maintenance and Repair Costs}} + \underbrace{R}_{\text{Replacement Costs}} + \underbrace{E}_{\text{Energy Costs}}, \qquad (2.1)$$

where all costs are in life-cycle present value or annual value dollars, net of any positive (cost-reducing) effects, and adjusted for taxes and incentives.

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[1] "Present value dollars" means that all past, present, and future costs are expressed as a time equivalent dollar amount at the present. Annual value dollars means that all costs are converted to a time equivalent, level amount recurring annually over the evaluation period. The discounting process, as this time adjustment is called, is described in section 3.

2.3.2 Net Benefits (Net Savings) (B-C)

The net benefits method finds the difference between the life time dollar energy savings from an investment in energy conservation and its life time dollar costs. This method is used to convert the analysis of an investment in energy conservation, involving for the most part cost increases and cost avoidances, into a standard benefit-cost format where cost avoidances (energy savings) are defined as benefits. As with the analysis of total life-cycle costs, net savings may be expressed in either present value or annual value dollars. The method involves the same cost elements and arrives at the same conclusion as the total life-cycle costing method, but is formulated somewhat differently.

Following is a general formula for finding the net benefits (net savings) from an investment in energy conservation:

Net Benefits or Net Savings (dollars) — Reduction in Energy Costs — Differential Purchase and Installation Costs — Differential Salvage Value — Differential Maintenance and Repair Costs — Differential Replacement Costs

$$(B - C) = E^* - (P^* - S^* + M^* + R^*), \qquad (2.2)$$

where all costs are in life-cycle present value or annual value dollars and are adjusted for taxes and incentives, and the asterisks adjacent to the symbols indicate differences in values between the building in its original state and after the energy conservation investment.

2.3.3 Savings-to-Investment (Benefit/Cost) Ratio (SIR)

The savings-to-investment ratio is a type of benefit/cost ratio that is often used when most of the cash flows are negative, i.e., costs. It expresses energy savings net of maintenance and repair costs, as a numerical ratio to the sum of investment costs and replacement costs less salvage value. Like the two preceding techniques, this technique is based on discounted cash flows. However, savings and costs are expressed as a ratio rather than as a dollar amount. The higher the ratio, the more dollar savings that are realized per dollar of investment cost.

Following is a general formula for computing the ratio of savings to investment-related costs:

Savings-to-Investment Ratio		Reduction in Energy Costs		Differential Maintenance and Repair Costs		Differential Purchase and Installation Costs		Differential Salvage Value		Differential Replacement Costs	
SIR	=	(E*	-	M*)	÷	(P*	-	S*	+	R*),	(2.3)

where all costs are in life-cycle present value or annual value dollars and are adjusted for taxes and incentives, and the asterisks adjacent to the symbols indicate differences in values due to the energy conservation investment.

2.3.4 Internal Rate of Return (IRR)

The internal rate-of-return technique finds the interest rate which, when used to discount life-cycle savings and costs, makes the two exactly equal and thus reduces net savings to zero. This interest rate indicates the rate of return on the investment. The rate of return is then compared to the investor's minimum acceptable rate of return to determine if the investment is desirable.

Unlike the preceding three techniques, the internal rate-of-return technique does not require the inclusion of a prespecified discount rate in its computation. Rather, the technique solves for the rate of interest which indicates the percentage yield on the investment. The analysis may be made in either present value or annual value dollars.

The rate of return is generally calculated by a structured process of trial and error, by which various compound rates of interest are used to discount cash flows until a rate is found for which the net value of the investment is zero. The method may be described algebraically in general terms as follows:

Find i, such that

(i = the Internal Rate of Return)

$$[\bar{E} \cdot a] - [\bar{P} - (\bar{S} \cdot b) + (\bar{M} \cdot c) + (\bar{R} \cdot b)] = 0, \qquad (2.4)$$

$\bar{E}$ = Reduction in Energy Costs
a = Discount Factor for Interest Rate i (UPW*, i, N)
$\bar{P}$ = Differential Purchase and Installation Costs
$\bar{S}$ = Differential Salvage Value
b = Discount Factor for Interest Rate i (SPW, i, j)
$\bar{M}$ = Differential Maintenance and Repair Costs
c = Discount Factor for Interest Rate i (UPW, i, N)
$\bar{R}$ = Differential Replacement Costs
b = Discount Factor for Interest Rate i (SPW, i, j)

where all costs are adjusted for taxes and incentives, and the bars over the symbols indicate that the cost differences have not yet been converted to present or annual values. The symbols a, b, and c refer to discounting factors incorporating the interest rate, i.[1]

2.3.5 Discounted Payback (DPB)

This evaluation technique measures the elapsed time between the point of an initial investment and the point at which accumulated savings, net of other accumulated costs, are sufficient to offset the initial investment. As for the other evaluation techniques, costs and savings should be adjusted to take into account the cost of money. (If the cost of money is not included, the technique is called "simple payback.") For the investor who requires a rapid turnover of investment funds, the shorter the length of time until the investment pays off, the more desirable the investment. However, a shorter payback time does not always mean a more economically efficient investment.

The general algebraic expression for determining the discounted payback period is the following:

[1] The discounting factors and corresponding symbols such as UPW* are described in detail in section 3.

Find y (Time to Payback) such that

Summation from time of investment to payback ($\sum_{j=1}^{y}$); Reduction in Energy Costs in year j (E_j^*); Differential Maintenance and Repair Costs in year j (M_j^*); Differential Replacement Costs in year j (R_j^*); Differential Salvage Value in year j (S_j^*); Differential Purchase and Installation Costs (P^*)

$$\sum_{j=1}^{y} (E_j^* - M_j^* - R_j^* + S_j^*) = P^*, \qquad (2.5)$$

where all costs are in either present value or annual value dollars and adjusted for taxes and incentives.

2.3.6 Advantages, Disadvantages, and Recommended Applications of Alternative Techniques

Although these five evaluation techniques are similar, they are also sufficiently different that they are not always equally appropriate for evaluating all types of energy conservation investment decisions. For some types of decisions, the choice of technique is more critical than for others. The choice is usually not critical, for example, in simple "accept-reject" investment decisions where the problem is to determine if a given conservation measure will save more than it costs. Any of the five techniques will usually work in this case. Following, for example, is a list of the criteria that must be met for each of the techniques if an investment is to be accepted simply on the basis of saving more than it costs:

TLCC technique -- the total life-cycle costs of a building or building system must be lowered as a result of the energy conservation investment.

B-C technique -- net dollar savings must be positive as a result of the energy conservation investment.

SIR (B/C) technique -- the ratio of dollar savings to investment-related costs from energy conservation must be greater than one.

IRR technique -- the compound rate of interest that equates dollar benefits and dollar costs from the energy conservation investment must be greater than the investor's minimum attractive rate of return.

DPB technique -- the time to discounted payback must be significantly shorter than the expected life of the project and there must be no costs after the payback time that are sufficiently large to offset the savings.

On the other hand, the choice of evaluation techniques usually is important for determining the priority to give to competing conservation investments when a limited budget must be allocated among those competing investments. For this purpose, either the savings-to-investment (benefit/cost) ratio technique or the internal rate-of-return technique is recommended. These techniques are preferred because they both reflect the return per dollar spent and can be used to rank investment projects in order of their return, such that a combination of investment projects can be selected that will result in the largest total return for a given conservation budget.

In the case where a fast turnaround on investment funds is required, the payback method is recommended. The other techniques, although more comprehensive and accurate for measuring an investment's life time profitability, do not measure the time required for recouping the investment funds.

For determining the economically efficient size of a conservation investment, any of the techniques will usually work, provided they are used correctly. The analysis of total life-cycle costs or the net savings (net benefits) technique is recommended for this purpose, however, because they are less likely to be misapplied. As long as the combined life-cycle costs of the conservation measures and of the energy consumption fall with added investment, it pays to increase the investment.[1] Likewise, as long as the net savings increase, it pays to increase the investment. The other techniques can be used to efficiently size an investment only if they are applied to increments in the investment rather than to the total investment.

Following are brief summaries of the principal strengths and weaknesses of each technique:[2]

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[1] This condition holds in theory only if there are no budget limitations; however, it often holds in practice because of the difficulty of simultaneously equating the marginal return on all energy conservation investments, the condition for determining the economically efficient level and combination of energy conservation investments if the budget is limited.

[2] For a more in-depth description of these methods, see Eugene L. Grant and W. Grant Ireson, Principles of Engineering Economy, 5th ed. (New York: The Ronald Press Company, 1970); E. J. Mishan, Cost-Benefit Analysis: New and Expanded Edition (New York: Praeger, 1976); and Ajit K. Dasgupta and D. W. Pearce, Cost-Benefit Analysis: Theory and Practice (New York: Harper and Row, 1972).

The total life-cycle costing technique is effective for determining if a conservation investment will save more than it costs and for finding the most economically efficient size of an investment. However, it is not dependable for allocating a limited budget among competing conservation investments to obtain the highest net savings for the entire budget, because it does not distinguish, for example, between a costly project with a given net savings and a less costly project with the same net savings. That is, the technique provides no measure of the return on the investment dollar.

The net benefits (savings) technique has essentially the same advantages and disadvantages as the total life-cycle costing technique; in fact the two techniques are generally interchangeable.

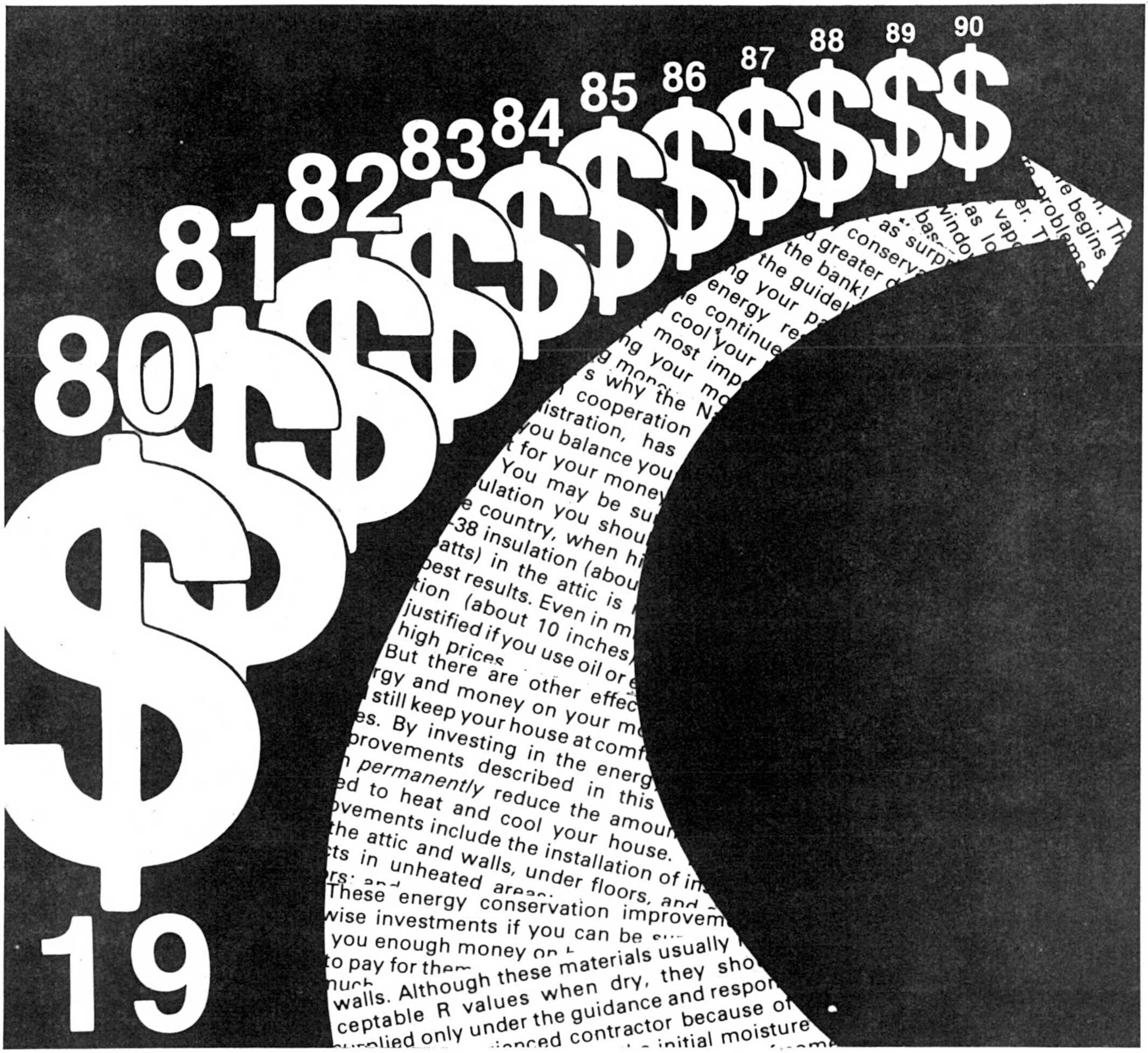
The savings-to-investment (benefit/cost) ratio technique offers an advantage over the two preceding techniques by providing a measure that can be used to rank alternative projects to determine the most profitable group of investments for the investor with a limited budget. It can also be used to determine the optimal size of a project if it is computed for increments in the investment size. However, it is often misapplied in sizing projects. Because the ratio on the total investment tends to fall before the optimal investment size is reached, its use may lead to undersizing investments, i.e., investing in too little conservation.

The internal rate-of-return technique offers a unique characteristic that is thought by some to be an advantage: not requiring the specification of a discount rate.[1] However, it is nevertheless necessary to estimate the minimum attractive rate of return (which is, in effect, a discount rate) against which the calculated internal rate of return must be compared to determine the desirability of an investment. This technique, like the savings-to-investment (benefit/cost) ratio technique, has the advantage of indicating the relative economic efficiencies of alternative investments, and, therefore, can be used to rank competing conservation projects.

Possible disadvantages of the internal rate-of-return technique are that it can be cumbersome to calculate manually and may under certain conditions result in indeterminant or multiple solutions. Also like the savings-to-investment ratio technique, the internal rate-of-return technique has the disadvantage of being subject to misapplication in the sizing of projects. As an investment is expanded, the rate of return on the overall investment may fall, while the rate of return on the additional investment may continue to exceed the investor's minimum attractive rate of return. As in the other case, this problem can be overcome by using the technique to evaluate incremental changes in the investment rather than the total investment.

[1] See section 3 for an explanation of the discount rate.

The discounted payback technique has the advantage of providing a measure of the period required to recover funds, a factor that may be critical to speculative investors or to investments whose principal assets have highly uncertain life expectancies. This feature is, however, often overemphasized; and less efficient, short-term investments are selected over more efficient, long-term investments. Where the expected time to recoup investment funds is a critical factor, it is recommended that the payback measure be supplemented with one of the four comprehensive, life-cycle evaluation techniques. The principal disadvantage of the payback method is that, even when based on discounted benefits and costs, it does not provide a full measure of an investment's profitability because it does not include benefits and costs that may occur after the point of payback is reached. The point of payback is simply a minimum break-even point.



3. Discounting

Initial investment costs, i.e., costs incurred at the time of construction or retrofitting, generally comprise a large proportion of the costs of energy conservation. The benefits, on the other hand, typically accrue over the life span of the project in the form of yearly energy savings. For a valid comparison of benefits and costs that accrue at different points in time, it is necessary to put them all on a time equivalent basis. The method for converting cash flows to a time equivalent basis is called discounting.

The value of money is time dependent for two reasons: first, inflation[1] erodes the buying power of the dollar, and second, money can command resources that can be used productively over time to yield a return over and above inflation. For these two reasons, a given dollar amount today will be worth more than that same dollar amount a year later. For example, if an investor were willing to purchase a one-year treasury bill (i.e., allow the Government the use of a sum of money for a one-year period) with a return of 12 percent interest per annum, then the 12 percent rate of interest indicates the price at which the investor is willing to trade present dollars for future dollars. The stronger the desire for money now rather than in the future, the higher the rate of interest required to increase future cash flows to make them equal to a given value today. The rate of interest for which an investor feels adequately compensated for receiving money in the future rather than having it now is the appropriate rate to use for converting future sums to present time equivalent sums or present sums to future time equivalent sums, i.e., the rate of interest for discounting cash flows for that particular investor. This rate is often called the discount rate, and is variously referred to as the rate which reflects an investor's "time value" or "opportunity cost" of money.

To evaluate correctly the economic efficiency of an energy conservation investment, it is necessary to convert, or "discount," the various expenditures and savings that accrue over time to equivalent values at some common time. Discounting can be accomplished by applying interest or discount formulas to the cash flows. There is a specific discount formula for each type of cash flow: a single compound amount (SCA) formula to convert a present amount to a time equivalent future value, a single present worth (SPW) formula to convert a future amount to a time equivalent present value, a uniform compound amount (UCA) formula to convert a stream of annually recurring amounts to a time equivalent future value, a uniform sinking fund (USF) formula to find the annually recurring amount that is the time equivalent of a future amount, a uniform capital recovery (UCR) formula to find the annually recurring amount that is the time equivalent of a present value, and a uniform present worth (UPW) formula to find the present value equivalent of an annually recurring amount. Additionally, there are discount formulas for finding the present and annual time equivalent values of a series of payments or receipts that change in amount over time. One of these formulas that is particularly useful in evaluating energy-related investments allows for the escalation of prices over time. This formula is referred to here as the modified uniform present worth (UPW*) formula. Each of the discount formulas listed here is included in Appendix B, where its standard notation and algebraic form are given.

For each discount formula, a set of discount factors can be calculated based on an amount of $1.00 and on specific discount rates, times, and, if applicable, energy price escalation rates. Tables of discount factors (not usually inclusive of energy price escalation) appear

[1] While it is possible that deflation might also occur, in recent years inflation has been more common.

in most engineering economics textbooks. Tables of factors for selected discount rates are provided in Appendix C of this report, and for selected discount rates and energy price escalation rates, in Appendix D. The discount factors can be used as simple multiplicative numbers, in lieu of the corresponding discount formulas, to perform the discounting procedure. The use of the factors offers the advantage of greater computational ease.

The remainder of this section illustrates how to convert various types of cash flows to a common time using the discounting procedure, in order to derive an investment's total life-cycle costs. Emphasis is on the use of discount factors rather than formulas. Discounting is illustrated in a sample problem of purchasing, installing, operating, and maintaining a heat pump. This type of cost measure would be required, for example, for comparing the life-cycle costs of a heat pump to those of an alternative heating/cooling system.[1]

The life-cycle cost calculations are given for two reference times. The first is the present, and is therefore called a present value. The second is based on a yearly time scale, and is called an annual value. These two reference points are the most common in economic evaluations of investments.[2] When the discounting procedures are applied properly, the present value and the annual value of an investment are mathematically time equivalent and will lead to the same investment decisions. (The life-cycle dollar costs of an investment of more than one year's duration will by necessity always be higher when expressed as a present value than when expressed as an annual value, because the present value measure incorporates the sum of discounted cash flows over the entire life-cycle, whereas the annual value measure amortizes, or spreads, the sum of discounted cash flows over the life. Nevertheless, the two measures are equivalent values in time. This equivalence is demonstrated in the heat pump illustration.)

The assumptions for the heat pump problem are as follows: (1) the residential heat pump costs $1,500, installed;[3] (2) the heat pump has a useful life of 15 years; (3) the system

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[1] The life-cycle costs in the sample problem are purely hypothetical for the purpose of illustrating the discounting procedure, and are calculated only for the heat pump and not for alternative heating/cooling systems. To evaluate alternative systems would require similar calculations of their life-cycle costs.

[2] The future is a third reference point in time sometimes used in discounting. If the base reference point for project analysis is the time when the building is constructed, for example, all costs to be incurred prior to construction such as planning, design, and land acquisition must be carried forward to the future time of construction in order to make time equivalent comparisons. Appendices B and C show respectively discount formulas and factors for discounting cash flows to present, annual, and future values.

[3] The $1,500 is for the heat pump itself and not for the duct system.

has annual maintenance costs of $50 fixed by contractual agreement over its useful life; (4) a compressor replacement is required in the eighth year at a cost in that year's dollars of $400; (5) evaluated at today's electricity prices, a year's electricity cost for using the heat pump would be $425; (6) electricity prices are projected to escalate at a rate of 7 percent per annum including inflation; (7) the discount rate is 10 percent including inflation; and (8) no salvage value is expected at the end of 15 years.

Total costs of the heat pump system include costs of purchase and installation, maintenance, replacing parts, and electricity for operation. Using the present as the common reference point, we need to convert each of these costs to the present before adding them. If we assume that the purchase and installation occurs at the present, the $1,500 is already in present value terms.

Table 3.1 illustrates how to convert the other cash flows to present values. The first task is to convert the stream of annual maintenance costs to its present value. The maintenance costs, as shown in the cash flow diagram of table 3.1, are $50 per year, measured in dollars of the years in which they occur. The triangle indicates the value to be found. We follow the practice here of compounding interest at the end of each year, so that costs (and benefits) in the future are always considered to occur at the end of the year in which they arise. The present refers to the beginning of year one.

The discounting operation for calculating the present value of maintenance costs (last column of table 3.1) is to multiply the annual maintenance costs times the uniform present worth (UPW) factor. The UPW factor is the multiplicative number taken from table C-3, column 7, for 15 years and a 10 percent discount rate. The UPW factor is the appropriate choice in this case because the costs are annually recurring. Given the discount rate of 10 percent, Appendix C is searched for the table that provides 10 percent discount factors. Finding 10 percent in table C-3, we look for the UPW factor (column 7) for 15 years. Moving down column 1 to where n = 15 and across to the UPW factor in column 7, a UPW factor of 7.606 is found. Multiplying this factor by $50 gives a present value of maintenance of $380.[1] Thus, with a discount rate of 10 percent, the investor should be indifferent between an initial cost of $380 and an annually recurring cost of $50 for 15 years, other things being equal. Note that the $380 present value equivalent of $50 per year incurred in each of 15 years is much less than the simple sum of $50 for 15 years (i.e., $750). This illustrates why discounting is required to achieve comparable statements of time-distributed costs and benefits evaluated at different points in time.

The second step is to convert the one-time future cost of compressor replacement, $400, to its present value. The operation for calculating the present value of compressor replace-

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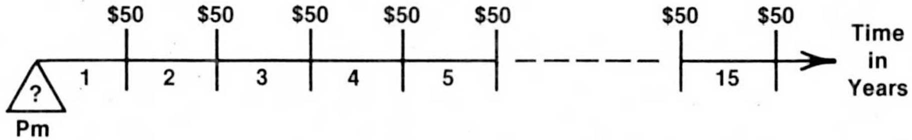
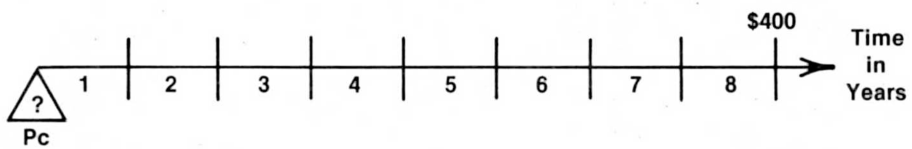
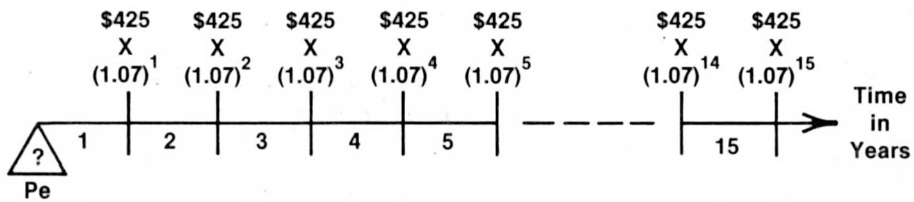
[1] Costs are rounded to the nearest dollar in table 3.1.

Task Description[a]	CASH FLOW DIAGRAM	Discounting Operation[b]
(Find P, Given A) Find the Present Value (Pm) of the $50 Annual Maintenance Costs (Am) Over 15 Years.		Pm = Am • UPW Pm = $50 (UPW, 10%, 15 yrs.) Pm = $50 (7.606) = $380.
(Find P, Given F) Find the Present Value (Pc) of the $400 Future Cost of Replacing Compressor (Fc) at End of 8 Years.		Pc = Fc • SPW Pc = $400 (SPW, 10%, 8 yrs.) Pc = $400 (0.4665) = $187.
(Find P, Given A with Escalation) Find the Present Value (Pe) of the Annual Electricity cost (Ae) Over 15 Years Given That a Year's Cost at Present Prices is $425 and Electricity Cost Escalation is Projected at 7% Per Year.		Pe = Ae • UPW* Pe = $425 (UPW*, 10%, 15 yrs., 7% Escalation) Pe = $425 • 12.1092 = $5,146.
	Find the Total Present Value of the Heat Pump (Ph) Over 15 Years.	Ph = Purchase and Installation Cost + Pm + Pc + Pe Ph = $1500 + $380 + $187 + $5146 Ph = $7213

[a] P = Present Value   A = Annual Value   F = Future Value

[b] UPW = Uniform Present Worth Factor   SPW = Single Present Worth Factor   UPW* = Uniform Present Worth Factor with Energy Escalation

TABLE 3.1 How to Determine Total Life-Cycle Costs in Present Value Dollars of a Heat Pump for Heating and Cooling

ment is to multiply the future cost of the compressor replacement times the single present worth (SPW) factor. Again we refer to table C-3 in Appendix C. Moving down column 1 to where n = 8, the year of the replacement, and across to the SPW factor in column 3, a value of .4665 is found. Multiplying this factor by $400 gives a present value cost of the compressor replacement of $187, as shown in the last column of table 3.1. Again note that discounting makes a significant difference in the actual measure of costs. Failing to discount the $400 would result in an overestimate of cost in this case of 214 percent ($400/$187).

The third step is to convert the annual electricity cost of heating and cooling to its present value. The yearly electricity cost of $425, evaluated at the present price of electricity, is shown in table 3.1. In addition, a price escalation rate for electricity of 7 percent per annum over the 15 years is assumed. Appendix D provides tables of modified uniform present worth (UPW*) factors that combine energy escalation rates from 1 to 10 percent with discount rates of 8, 10, and 12 percent.

The discounting operation for finding the present value of electricity cost (shown in table 3.1) is to multiply the annual electricity costs times the appropriate UPW* factor in Appendix D. Finding year 15 in the first column of Appendix table D-2, look across the table for the UPW* factor under the escalation rate of 7 percent. The value is 12.1092. Multiplying this factor by $425 gives a present value of electricity costs of $5,146. Note once again that failing to discount (i.e., simply adding annual electricity expenses in current prices) would overestimate costs by 124 percent ($6,375/$5,146). Discounting with a UPW factor that does not incorporate energy price escalation would underestimate costs by 63 percent ($3,233/$5146).

The final operation described in table 3.1 is to sum purchase and installation costs and the present values of maintenance, compressor replacement, and electricity costs. Total life-cycle costs of the heat pump in present value terms are $7,213. This is the kind of cost figure a designer would need for comparing the cost effectiveness of a heat pump to alternative heating/cooling systems.

Table 3.1 provides a model for the designer who must calculate present values from all kinds of benefit or cost streams. That is, any distribution of values occurring in future years can be handled either with the SPW factor, the UPW factor, or the UPW* factor with energy price escalation.[1]

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[1] An exception is the treatment of future energy costs that are expected to escalate at changing rates over time. Several additional steps, beyond those illustrated here, are required to calculate the present value in that case.

Only one discounting operation is required to convert the present value costs of the heat pump to annual value terms.[1] The total present value amount is converted to the total annual value by multiplying it by the uniform capital recovery factor (UCR) for 10 percent and 15 years. The UCR factor, found in table C-3, is .13147. Multiplying this factor by the total present value of $7,213 gives the cost of the heat pump as $948 in annual value terms. Although the cost expressed in annual terms, $948, is different when expressed in present value terms, $7,213, the two figures are time equivalent values, made consistent through the application of discounting.

The discounting procedures described above are sufficient along with Appendices B, C, and D to handle most energy conservation investment problems. Using these discounting procedures together with the information presented in sections 2, 4, and 7, the building designer can formulate and solve many energy conservation investment problems.

Further examples of solutions to problems are given in sections 5, 6, and 7. The following section, 4, provides guidance in establishing values of key variables in evaluating energy conservation and solar energy investments.

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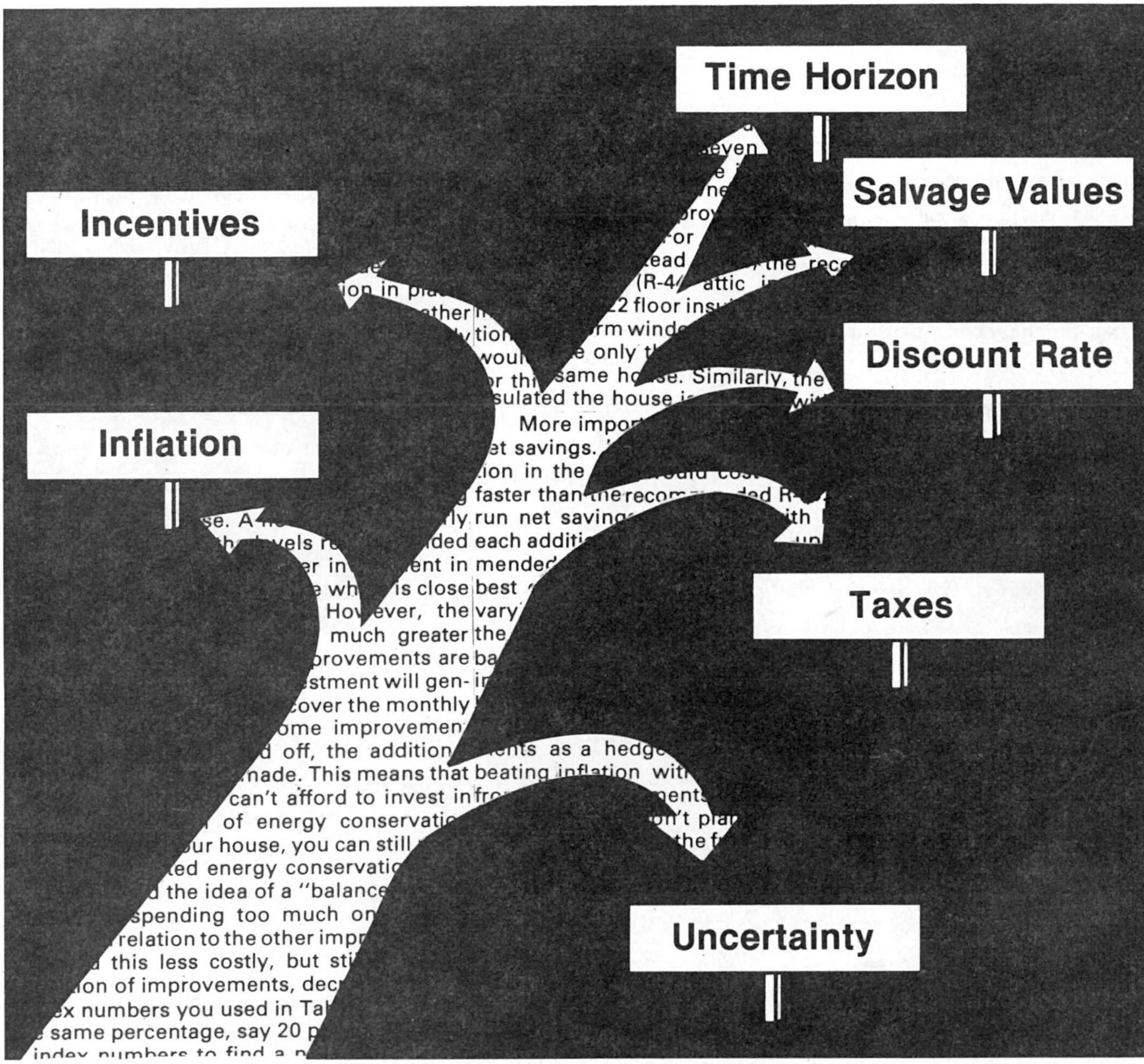
[1] Annual values are not the same as average yearly values; i.e., the installation cost of $1500, divided by 15 years, or $100 per year, will not be the annual value of installation costs. Because average yearly values do not include discounting, they give erroneous estimates of future benefits and costs.



4. Factors Affecting Costs and Savings

The purposes of this section are to discuss in more detail some of the significant factors that affect the outcome of an economic evaluation; to provide the designer guidance in selecting values for those factors; and to describe the impact of these factors on the economic viability of conservation investments.

4.1 TIME HORIZON

The time horizon is the period of analysis. For conservation investments it is the length of time over which costs and benefits from conservation are calculated. The time horizon is often called the "life cycle" in life-cycle cost analysis.

The selection of a time horizon may be based on some concept of investment life or on the personal time perspective of the investor. There is no rule-of-thumb time horizon that will be appropriate for all investment projects.

The life of a building, building system, or conservation investment is often used as the time horizon. Two common concepts of the life are the "useful life" and "economic life." The useful life is the period over which the investment has some value; i.e., the investment continues to conserve energy during this period. Economic life is the period during which the conservation investment in question is the least-cost way of providing that particular type of conservation. It is likely that the economic life will be shorter than the useful life, although in cases such as massive walls used in some passive solar energy projects, the useful life and the economic life may tend to coincide due to the typically high durability, low maintenance, and high replacement costs of the system. Economic life is more appropriate for making economic evaluations, but useful life is often easier to determine.

The actual selection of a time horizon will depend on the objectives and perspective of the builder/owner. A speculative builder who plans to build for immediate sale, for example, may view the relevant time horizon as that short period of ownership from planning and acquisition of property to the first sale of the building. Although the useful life of a solar domestic hot water heating system, for example, might be 20 years, the speculative builder might operate on the basis of a two-year time horizon, because the property is expected to change hands within that period. If the speculator does not expect to keep the long-run benefit of those solar energy savings through a higher selling price for the building, then the high first cost solar investment is unlikely to be economic. This type of reasoning accounts in part for the many speculative homes that have been built in the past with little regard for energy conservation.[1]

If the client requesting an economic evaluation of energy conservation investments does not specify a period of analysis, the designer or analyst must choose a time horizon. Legislation or guidelines may provide the answer for public buildings. Economic life or useful life of the project is often used. Building life is sometimes used and, at the least, constitutes a constraint on the selection of a time horizon. Mortgage lending periods for buildings, normally ranging from 20 to 30 years, provide an index of building life. Depreciation periods for business tax purposes represent another possible index. Government buildings are likely to be evaluated over a longer time horizon than private buildings because they tend to have only one owner, are built to last a long time, and are well main-

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[1] For a more complete discussion of how limited time horizons of speculative builders affect energy conservation investments, see Harold E. Marshall, "Comment on the Pros and Cons of Life-Cycle Costing," 1976 Conference on Improving Efficiency and Performance of HVAC Equipment and Systems for Commercial and Industrial Buildings, Conference held at Purdue University, April 11-14, 1976.

tained. As public awareness of the costs of energy and potential savings to be had from conservation increases, and as the anticipated savings from conservation become capitalized in the resale prices of buildings, however, the time horizons for private sector conservation investments are likely to increase.

From the perspective of national economic efficiency, a time horizon based on a concept such as economic life is preferred to one based on a short speculative period. To evaluate conservation investments on the basis of costs and benefits for a short, speculative holding period might be economical to the speculator in a market where buyers have incomplete information about the potential benefits from energy conservation design. However, such an approach would be inefficient for society in general, because potential long-term net benefits from conservation would be foregone.

The impact of varying the time horizon depends in part upon three related factors -- the discount rate, the rate of fuel price escalation, and salvage value. How these factors interact will be discussed and illustrated graphically in the sections that follow.

4.2 DISCOUNT RATE

The selection of a discount rate may be guided by rates of return on alternative available investment opportunities, by the cost of borrowing capital, or, in the case of public organizations, by legislative or executive requirements. The United States Office of Management and Budget (OMB), in Circular A-94, requires Federal agencies to use a discount rate of 10 percent for evaluating most government investments, including conservation investments in buildings.[1]

Private builders and building owners can select any discount rate they feel appropriate, based on their time preference. Economists tend to favor a discount rate based on the rate of return after taxes that an investor could earn on the best available alternative investments. If the rate of return on the next best investment opportunity were 12 percent, for example, then a discount rate of 12 percent would be used. If net benefits were not positive on a conservation investment discounted at 12 percent, this indicates that the investor would find other investments more economically attractive than the conservation investment.

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[1] This is a "real" discount rate, that is, it does not include inflation. The treatment of inflation is discussed later in this section. There are other rates required for certain types of investments. For example, for decisions on leasing or purchasing real property, OMB requires a discount rate of 7 percent.

If an investor is unsure of the rates of return on opportunities outside of energy conservation, the cost of borrowing[1] can be used as the discount rate. However, the opportunity earning rate should take precedence over the borrowing rate as an indicator of the appropriate discount rate. For a homeowner, a possible index is the return the investor might receive on a savings account.

To select the appropriate discount rate, the building designers might first ask the client if there are any Federal, State, or local government requirements regarding the discount rate. If not, the client might be asked for after-tax rates of return in other investments. Note that these might vary considerably by firm or industry.

Building clients may request that projects of high risk be evaluated with a higher discount rate than those with low risk. Risk can also be treated by basing benefit and cost estimates on probabilities of occurrence or by using sensitivity analysis.

Discount rates may be expressed in either "nominal" or "real" terms. A <u>nominal discount rate</u> includes both the effects of inflation and the real earning power of money invested over time.[2] A <u>real discount rate</u> reflects only the real earning power of money, and therefore is lower than a nominal rate would be, given the same conditions. A real rate is appropriate for evaluating investments if the general rate of inflation is not included in future cash flows; a nominal rate is appropriate if future cash flows are inflated. For example, if an investor were able to realize a return of 3 percent from his or her best investment during a period when there was no significant price inflation, the investor's real discount rate might be set at 3 percent and used to discount future costs and benefits estimated in constant dollars, that is, non-inclusive of inflation. If a return of about 8 percent were available from the same type of investment during a period when the general price inflation rate was 5 percent, the investor's nominal discount rate could be set at 8 percent and used to discount future costs and benefits estimated in current dollars, that is, inclusive of inflation.

The two approaches should give consistent results, and for some applications, the analyst will be indifferent whether the evaluation is performed using a real discount rate and constant dollar estimates of benefits and costs or a nominal discount rate and current dollar estimates of benefits and costs. However, in evaluating simple investment problems and problems where it is reasonable to assume that most cash flows inflate at the same rate, the use of a real discount rate and constant dollar estimates of benefits and costs may be simpler. (For

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[1] Note that net savings from energy conservation investments should be discounted whether the investment is financed through equity or borrowed funds.

[2] The nominal discount rate is often called the "market rate," because inflation and real earning power are reflected in market rates of interest.

examples, see section 7, Problems 7 through 11.) And in the case where tax effects are important and complex, and the inflation rate is variable among a number of cost items, the analyst may find it more convenient to work with a nominal discount rate and current dollar estimates of benefits and costs. (This approach is demonstrated in section 7, Problems 12 and 13.)

Where special account is to be taken of energy prices rising faster than other prices, the fuel escalation rate must be consistent with the discount rate. If a nominal rate of discount is used, for example, then the projected rate of the total change in energy prices must be used. On the other hand, if a real rate of discount is used, the differential rate of energy price change is appropriate, i.e., the projected escalation rate for energy prices apart from the average escalation rate of prices in general.[1]

Real rates ranging from about 2 to 10 percent and nominal rates ranging from about 8 to 15 percent appear to have been prevalent in the United States over the past decade. The 10 percent rate that OMB Circular A-94 requires for evaluating most government investments, including energy conservation, is a real rate.

Of the various factors affecting the net benefits of conservation investments, the discount rate is one of the most dramatic, in that a project that appears economic at one rate will often appear uneconomic at another rate. For example, a conservation project with positive net savings at a 6 percent discount rate might yield negative net savings if evaluated with a 9 percent rate.

As the discount rate is increased, the present value of any future stream of costs or benefits is going to become smaller. High discount rates tend to favor projects with quick payoffs over projects with benefits deferred to the future.

4.3 INFLATION

Inflation is a rise in the general price level reflecting a decline in the purchasing power of the dollar. Although all prices cannot be expected to rise or fall together and in the same amount, average price increases in specific and general categories of goods and services can be measured.[2] In making economic evaluations of energy conservation investments, it is important that price inflation as indicated by average price increases in the economy be adjusted for, such that a consistent unit of value is used to assess estimates of benefits and costs.

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[1] The differential escalation rate will be discussed further in section 4.3.

[2] For a description of price indices, see U.S. Department of Labor, Bureau of Labor Statistics, Monthly Labor Review, any issue.

Fuel prices have increased so rapidly in recent years (as shown in table 1.1) that they must be given special attention in evaluating energy conservation investments. Since benefits from conservation vary directly with fuel prices, assumptions regarding the change in fuel prices over time have a large impact on the predicted benefits of a conservation project. Projected energy prices are usually based on contractually stated prices, extrapolated trends from historical prices, or government/industrial predictions of future prices. The Energy Information Administration of the U.S. Department of Energy, for example, projects future prices of energy by fuel type, region of the country, and sector (residential, commercial and industrial), in constant dollars for the period 1980 to 1995.[1] Updates of price projections should be consulted periodically in order to obtain the most current price data in evaluating conservation investments.

Other prices affecting the benefits and costs of conservation investments over time are those related to operation, maintenance, and replacement. These prices, as well as energy prices, should be adjusted for inflation.

One way of handling inflation is to eliminate it from inflated cash flows by applying a price deflator index[2] to future inflated prices, thereby converting them to constant dollars in a common base year. The prices in constant dollars may still rise, but they will reflect estimated "real" price changes rather than changes due to general declines in the dollar's purchasing power. The constant dollar prices must then be discounted with a "real" discount rate to arrive at present or annual values. As indicated earlier, a second way of handling inflation is to discount cash flows that contain inflation with a "nominal" discount rate that reflects both the real changes in the value of money and the expected inflation rate. An alternative to these two ways of handling inflation is to project future cash flows in constant dollars, without inflation, at the outset by estimating all future costs and benefits in terms of today's value of the dollar. In this case, "differential" price escalation rates can be used to adjust those categories of costs that are expected to rise faster than prices in general (e.g., energy) and a real discount rate should be used in the life-cycle cost analysis.

The impact of inflation on the economic viability of conservation improvements depends on which prices are inflating most, as well as on institutional arrangements such as taxes.

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[1] "Federal Energy Management and Planning Programs; Methodology and Procedures for Life-Cycle Cost Analysis of Federal Buildings," Federal Register, Vol. 45, No. 16, Wednesday, January 23, 1980, Appendix C.

[2] For an explanation of the construction and use of price deflator indices see U.S. Office of Management and Budget Circular A-104, "Comparative Cost Analysis for Decisions to Lease or Purchase General Purpose Real Property," June 14, 1972.

For example, the higher the escalation rate of energy relative to other prices, the more economical conservation investments will appear. On the other hand, for commercial properties, depreciation writeoffs (based on the original "book value" of the investment) for tax purposes will become less significant with higher rates of general inflation, and capital gains taxes will become larger as resale values increase.

4.4 INCENTIVES

An incentive is a form of positive inducement, usually provided by a government agency, that encourages a particular type of behavior or action. Available incentives should be considered in economic evaluations of conservation investments because they affect the economic viability of an investment and its optimal size. Following are several examples of different kinds of incentives:

Grants are cash subsidies of specified amounts to purchasers of energy conservation equipment. The National State/Federal Combined Program for providing subsidies to residential users of solar hot water heaters is an example. The cost of a solar hot water heater to the recipient of a grant is the life-cycle cost of the system minus the government grant.

Taxes may be used as a means of providing several types of incentives. Income tax credits for conservation expenditures provide a subsidy by allowing specific deductions from the investor's tax liability. Property tax exemptions allowed for the tax obligations on conservation capital equipment (for example, solar collectors) eliminate the property taxes that would otherwise add to annual costs. Liberal allowances for income tax deductions for energy conservation expenses reduce annual costs. The imposition of higher taxes on nonrenewable energy sources raises their prices and encourages conservation investments. Elimination of the tax deductibility of business fuel expenses would further encourage investment in energy conservation.

Government cost sharing of a specified percentage of private sector conservation investments increases the attractiveness of conservation. The National Energy Act, for example, provides Federal cost sharing for schools and hospitals.

Loan interest subsidies that provide conservation loans at rates below the market rate reduce the borrowing costs and make energy conservation more economical.

Conservation designs that are uneconomical without incentives may in fact be cost effective if available incentives are included in the economic evaluation. Legislation, government agencies, and associations such as the National Conference of State Legislators are potential sources of information on available incentives for energy conservation.[1]

4.5 TAXES

In the previous section, taxes were examined in the context of a mechanism for providing incentives for energy conservation investments. This section describes the general effects of property taxes and income taxes on the economic viability of conservation investments.

Property taxes are annual levies on real property. Energy conservation investments that increase the cost of a building raise the value of that property, and thereby raise the property tax. This effect reduces the net savings from capital-intensive conservation investments.

Income taxes are annual levies on personal and business incomes. A positive effect for conservation investments is the deductibility from taxable income of interest on loans for conservation improvements. Another is the deductibility from taxable income of depreciation on conservation capital investments. A third effect of income taxes, a negative one, is the tax deductibility of fuel expenses for businesses. Because the fuel expenses of a profit-making enterprise are deductible as a business expense, after-tax dollar savings from energy conservation are less than the before-tax value.

4.6 SALVAGE VALUES

Salvage value is the residual value of an investment or investment component, net of disposal costs, when it is sold, scrapped, or otherwise removed from service or when useful life remains at the end of the project time horizon. The present value of the salvage value can generally be expected to decrease, other things equal, with (1) higher discount rates, (2) more rapid building or equipment deterioration, and (3) longer time horizons.

One index of salvage value is the amount that could be added to the selling price of a building because of the energy conservation investment. Or, one might estimate salvage value on the basis of the value remaining when investment costs are prorated over the life of the asset. Another approach is to base salvage value on replacement costs. Yet another approach is to base salvage value on the capitalized value of energy savings over the remaining life of the conservation investment. If the time horizon is the useful life, there will be no

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[1] See, for example, Robert M. Eisenhard, State Solar Energy Legislation of 1976: A Review of Statutes Relating to Buildings, National Bureau of Standards, NBSIR 77-1297, September 1977; Patrick W. Cooke and Robert M. Eisenhard, Building Energy Conservation Programs -- A Preliminary Examination of Regulatory Activities at the State Level, National Bureau of Standards, NBSIR 77-1259, June 1977.

salvage value, other than possibly scrap value of component parts. And even if potential energy savings remain, there will likely be little or no salvage value for the conservation investment if it is an integral part of a building with a poor resale market (e.g., a building in a declining neighborhood).

4.7 UNCERTAINTY

Estimates of benefits and costs from energy conservation design are only as good as the data used in making those estimates. Because some of the life-cycle costs and most of the life-cycle benefits from conservation design accrue in the future, the design community will often be uncertain as to the correct values to use in predicting future benefits and costs.

Two analytical techniques that can be used to help make decisions about conservation investments whose economic payoffs are uncertain are sensitivity analysis and probability analysis.

Sensitivity analysis tests the sensitivity of net benefits or rates of return to alternative values of key factors about which there is uncertainty. Although sensitivity analysis does not provide a single answer in economic terms, it does show decision makers how the economic viability of a conservation project changes as fuel price escalation, discount rates, time horizons, and other critical factors vary.

Figure 4.1 illustrates the sensitivity of fuel savings from a solar heating system to three critical factors: time horizons (0 to 25 years), discount rates (D equals 0, 5, 10, and 15 percent) and energy escalation rates (E equals 0, 5, 10, and 15 percent). The present value of savings is based on yearly fuel savings valued initially at $1,000.

Note that, other things being equal, cumulative savings increase over time, are lower with higher discount rates, and are higher with higher escalation rates. The huge impact of fuel price escalation is most apparent when comparing the top line of the graph (D = .10, E = .15) with the line next to the bottom (D = .10, E = 0). The present value of savings at the end of 25 years is about $50,000 for a fuel escalation rate of 15 percent, and only about $8,000 for a rate of zero percent, other things equal. Whereas the quantity of energy saved is the same, the dollar value varies widely due to the selection of the escalation rate.

Although impact scenarios such as those illustrated in figure 4.1 do not show the analyst what parametric values to choose, they do show decision makers the impact of alternative assumptions, and thereby may help them make better decisions regarding conservation investments with uncertain outcomes.

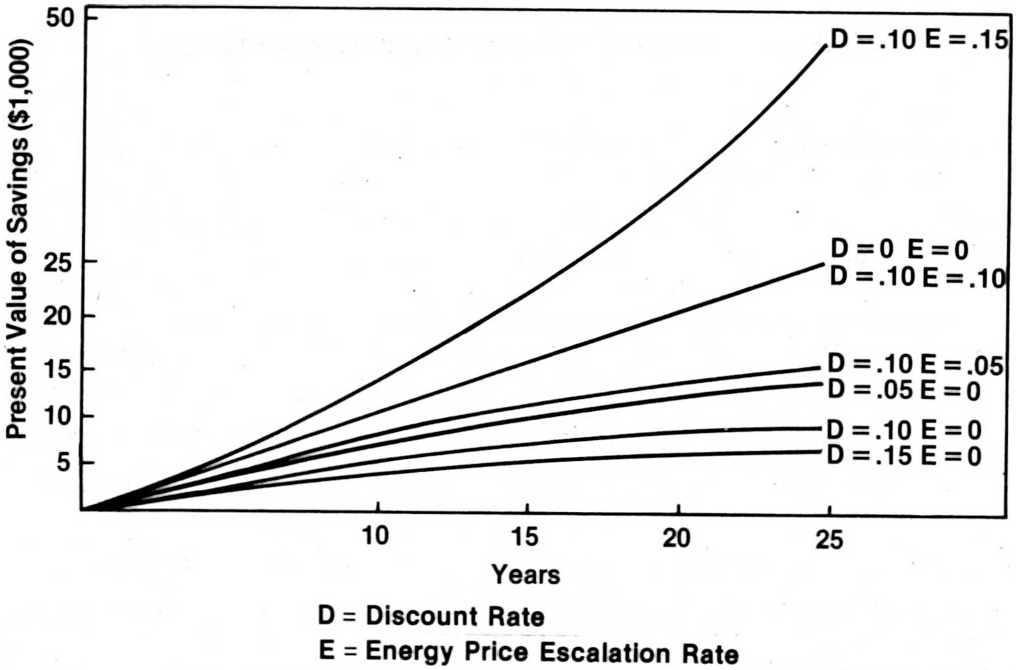

FIGURE 4.1 Sensitivity of Fuel Savings to Time Horizons, Discount Rates, and Energy Escalation Rates.

Probability analysis[1] can sometimes be used to evaluate the benefits and costs of an event whose expected chance of occurrence can be predicted. If historical data are available for existing technologies, probabilities may be determined. In the case of innovative technologies where no data base exists, computer simulation may be used to generate probability data.

Taking the heat pump illustration in section 3 as an example, if the probability distribution for the year of replacement of the compressor were given as shown in table 4.1, the expected value of the cost of compressor replacement, as measured in present value dollars, would be $193. Note that this is not the same as the $187 estimate shown in table 3.1. Although it is unlikely that the exact cost of replacing the compressor will be predicted using a probabilistic approach, over a large number of applications the difference between the actual cost and the predicted cost will generally be less than when a single point estimate is used.[2]

The factors affecting benefits and costs that are outlined in this section, the discounting procedures described in section 3, and the techniques of analysis introduced in section 2 are combined in the following two sections to provide comprehensive illustrations of economic evaluations of energy conservation designs in buildings.

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[1] Probability analysis is often called expected value analysis.

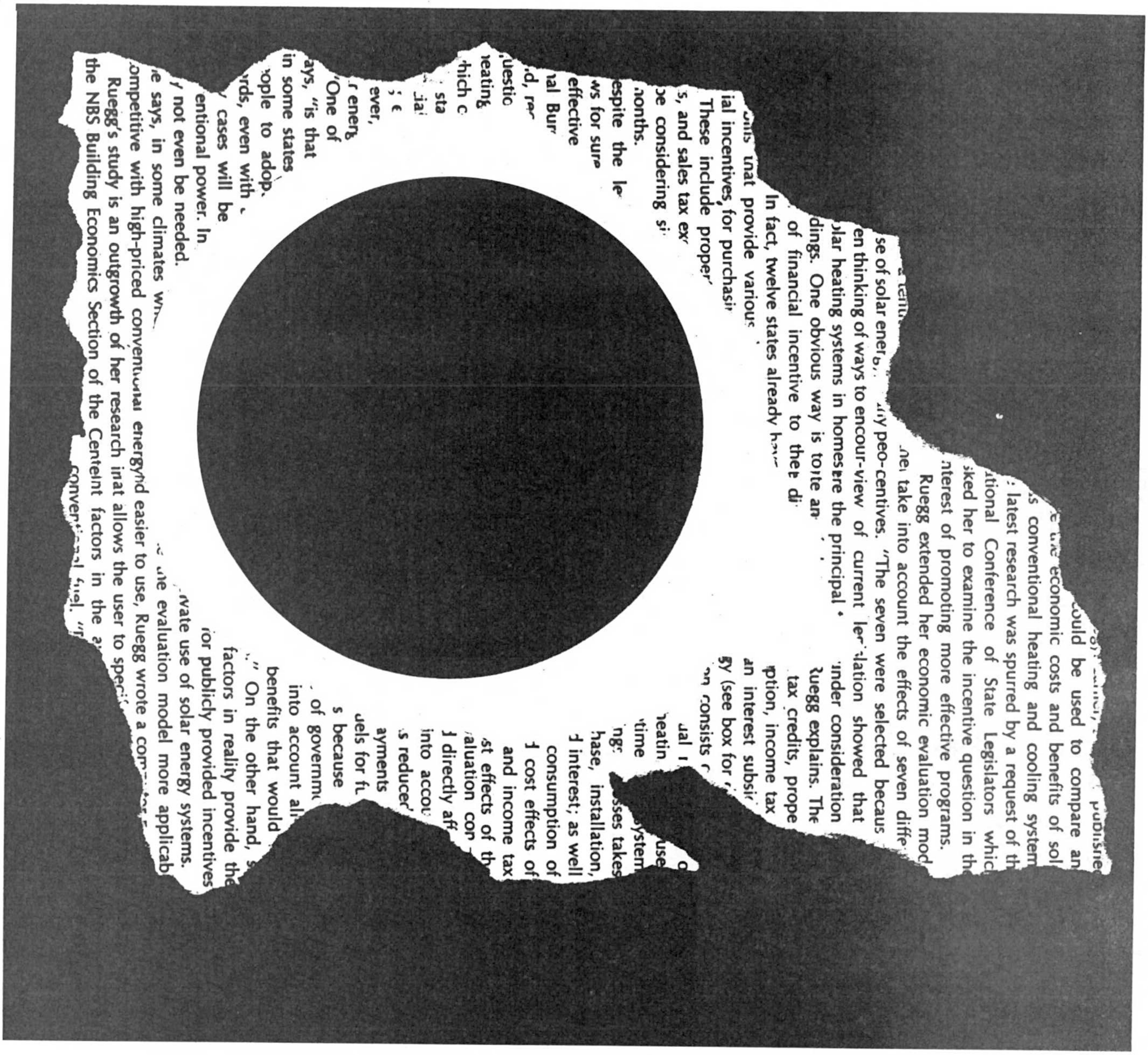
[2] This assumes a probability distribution that is representative of compressor replacement

TABLE 4.1 Expected Value of Compressor Replacement

Replacement in Year	Probability	Cost	Present Worth Factor[a]	Expected Present Value Cost[b]
6	0.1	400	.5645	$ 23
7	0.2	400	.5132	41
8	0.6	400	.4665	112
9	0.1	400	.4241	17
	Expected value of compressor replacement			$193

[a] A 10% discount rate is assumed.

[b] Costs are rounded to the nearest dollar



5. Solar Energy Case Illustration

5.1 PROBLEM DESCRIPTION[1]

Because the first costs of solar energy systems are relatively high and the savings are spread over time, it is usually advisable to make an economic evaluation prior to acquiring such a system. There are two main economic questions to answer: (1) will solar energy pay in a given application, and (2) what is the optimal design and size for the system? These

[1] This case illustration, including the tables and graphs, is based on a sample design problem from Rosalie T. Ruegg and G. Thomas Sav, Microeconomics of Solar Energy, National Bureau of Standards Report, In Press.

questions, in fact, are not separable because an economic feasibility study should focus on those systems that are efficiently designed and sized.

Substituting solar energy for conventional energy sources in a building may lower or raise the total life-cycle, energy-related costs of the building. Where solar energy is cost effective, the minimum-cost choice of space heating systems will tend to be a combination of solar energy providing some percent, f_s, of the building's heating requirements, and conventional energy providing the remaining percent, $100-f_s$, of the requirements. In addition, potential tradeoffs usually exist between meeting energy requirements by available energy sources and reducing the energy requirements by energy conservation. Adding insulation to the walls, for example, reduces the requirements for either solar or conventional energy. A full economic optimization of the energy components of a building would take into account investment tradeoffs among energy conservation techniques, solar energy, and conventional and other energy sources.

For the purpose of this illustration, the problem is limited to the choice of size for a heating/hot water system of a given design in a commercial building. The problem is both to find the most economically efficient solar energy system size, A*, that will provide the economically efficient percent, f_s^*, of energy requirements, and to determine the dollar savings associated with that economically sized system.

Following are descriptions of the building, its location, and its energy requirements; solar insolation; the solar energy system; and the economic assumptions required to analyze the problem:

Building:	16,800 ft^2 (1560.8 m^2), 3-story commercial office and laboratory
Location:	Albuquerque, New Mexico
Building energy requirements:	(See table 5.1)
Solar insolation:	(See table 5.1)
Collector:	4' x 8' (1.2 m x 2.4 m) flat plate collectors, selective absorption surface, tilted at 45°
Storage:	Assumed set at 15 lb of water (1.8 gal) per ft^2 (73 kg/m^2) of collector[1]
Economic Assumptions:	(See table 5.2)
Space heating and hot water alternatives:	Gas space heating and hot water systems alone or combined solar/identical gas backup systems

[1] The relationship of 15 lb of water storage capacity per ft^2 of collector area corresponds to a widely used "rule-of-thumb" for storage sizing based on studies of storage costs and useful energy delivery. [See, for example, Frank Kreith and Jan F. Kreider, Principles of Solar Engineering (New York: McGraw-Hill Book Company, 1978) pp. 428-429.]

TABLE 5.1 BUILDING LOAD AND INSOLATION DATA FOR SAMPLE DESIGN PROBLEM

Month	Space heating load[a] 10^6 Btu (L_H) (1)	Hot water load[b] 10^6 Btu (L_W) (2)	Combined space heating and hot water load 10^6 Btu (L) (3) = (1) + (2)	Solar energy incident on collector 10^3 Btu/ft^2 of collector[c] (I) (4)
January	104.7	14.0	118.7	57.3
February	97.2	12.7	109.9	60.5
March	88.3	14.0	102.3	69.0
April	83.3	13.6	96.9	71.2
May	54.0	14.0	68.0	83.2
June	27.4	13.6	41.0	77.6
July	24.2	14.0	38.2	67.2
August	33.8	14.0	47.8	74.1
September	51.1	13.6	64.7	58.9
October	72.9	14.0	86.9	69.0
November	88.6	13.6	102.2	53.0
December	109.2	14.0	123.2	57.0
Annual Total	834.7	165.1	999.8	798.0

[a] Determined by the NASA Energy and Cost Analysis Program (NECAP) using hourly weather data.

[b] Based on a constant 3 gallons-per-minute hot water usage during an 8 hour day for an occupancy of 118 people.

[c] Not adjusted for system technical efficiency nor demand patterns; i.e., col. 4 shows the available solar energy striking the collector, not the quantity of useful energy delivered by the system.

TABLE 5.1-M BUILDING LOAD AND INSOLATION DATA FOR SAMPLE DESIGN PROBLEM

Month	Space heating load[a] GJ (L_H) (1)	Hot water load[b] GJ (L_W) (2)	Combined space heating and hot water load GJ (L) (3) = (1) + (2)[c]	Solar energy incident on collector MJ/m^2 of collector[d] (I) (4)
January	110.5	14.8	125.2	651
February	102.6	13.4	116.0	687
March	93.2	14.8	107.9	784
April	87.9	14.3	102.2	809
May	57.0	14.8	71.7	945
June	28.9	14.3	43.3	881
July	25.5	14.8	40.3	763
August	35.7	14.8	50.4	842
September	53.9	14.3	68.3	669
October	76.9	14.8	91.7	784
November	93.5	14.3	107.8	602
December	115.2	14.8	130.0	647
Annual Total	880.7	174.2	1054.8	9063

[a] Determined by the NASA Energy and Cost Analysis Program (NECAP) analysis using hourly weather data.

[b] Based on a constant 2 litre-per-second hot water usage during an 8 hour day for an occupancy of 118 people.

[c] Due to rounding in converting to metric units, this equation does not always hold.

[d] Not adjusted for system technical efficiency nor demand patterns; i.e., col. 4 shows the available solar energy striking the collector, not the quantity of useful energy delivered by the system.

TABLE 5.2 SOLAR CASE ECONOMIC ASSUMPTIONS

Mortgage Interest Rate = 9%

Mortgage Life = 20 years

Percent of Loan required as down payment = 0

Nominal Discount Rate = 10%

Nominal Annual Rate of Conventional Fuel Price Escalation = 9%

General Long-Term Rate of Inflation = 5%

Conventional Fuel Sales Tax Rate = 4%

Combined Federal and State Corporate Income Tax Rate = 51%

Effective Property Tax Rate = 3%

Recurring Cost (maintenance, repair, replacement) Rate = 2% of Purchase and Installation Costs

Declining Balance Depreciation Rate = 200%

Depreciation Write-off Life = 10 years

Solar Energy System Life = 20 years

Variable Solar Energy System Costs = $\$20/ft^2$ ($\$215/m^2$) of collector area (A)

Fixed Solar Energy System Cost = $2500

Conventional Energy System Efficiency = 60%

Btu Content of Conventional Energy = 10^6 Btu/10^3 CF Natural Gas

Current Price of Conventional Energy = $\$3.00/10^3$ CF ($\$.11/m^3$)

Government Grants = None

Government Tax Credits = None

5.2 SOLUTION

To determine the optimal size of the solar energy system and the expected net life-cycle savings from that system, an iterative approach can be used to calculate either the total life-cycle costs associated with alternative combinations of the solar and gas conventional systems, or the net life-cycle savings attributable to the solar energy system. Using the first technique, the objective is to minimize the total life-cycle costs of the space heating/hot water system, while meeting the comfort and hot water requirements of the building. Using the second technique, the objective is to maximize the net savings from using solar. Both approaches will lead to the same investment decision.

In simple terms, the equation for computing the present value (PV) of net savings from solar energy (NS_s) is the following:

PV solar energy net savings

PV energy costs, conventional system only

PV energy costs, combined solar/conventional systems

PV, non-energy costs combined solar/conventional systems

PV non-energy costs, conventional system only

$$NS_S = (F_c - F_s) - (C_s - C_c) \qquad (5.1)$$

For the case in which there is no difference in fuel type, fuel price, equipment efficiency, and tax rates for the conventional energy system used alone and as the solar backup system, the difference between F_c and F_s in eq. (5.1) may be expressed in more detail as follows:

Reduction in PV energy costs with solar

Marginal income tax rate

Price per sales unit of energy, e.g., $/10^3CF

Total yearly energy load, e.g., Btu/year

Fraction of L supplied by solar

Efficiency rating of conventional energy equipment

Energy content per sales unit of energy

Uniform present worth factor adjusted for energy price escalation

$$(F_c - F_s) = [(1 - t)\ P_c \cdot L \cdot f_s \cdot \delta^{-1} \cdot \beta^{-1} \cdot UPW^*] \qquad (5.2)$$

For the case in which there is no difference in equipment costs, maintenance, repair and replacement costs, salvage value, life and taxes for the conventional energy system used alone and for the backup system to solar, these values may be omitted from the analysis, and the difference between C_s and C_c in eq. (5.1) may be expressed in more detail as follows:

Differential PV non-energy costs attributable to solar; Fixed cost of the solar energy system; Variable cost of the solar energy system; Area of the solar energy collector, e.g., ft^2; Downpayment as a percentage of the solar purchase and installation cost; Uniform capital recovery factor (based on the mortgage loan rate and loan life) for finding the amount of monthly or yearly mortgage payments; Uniform present worth factor for finding the present value of mortgage payments; Government grants; Income tax credits

$$(C_s - C_c) = [(F_x + vA)\ (a + ((1 - a) \cdot UCR \cdot UPW)) - G - T -$$

Solar salvage value; Single present worth factor; Solar maintenance costs; Uniform present worth factor; Solar replacement costs; Single present worth factor; Present value of property taxes due to solar; Present value of solar capital depreciation deductions; Present value of solar loan interest deductions from taxable income

$$S\ (SPW) + M\ (UPW) + \sum_{j=1}^{n} R_j\ (SPW_j) + P - D - W]. \qquad (5.3)$$

To find the solar energy system size with the maximum net dollar savings, we can apply eq. (5.2) and (5.3), using the assumptions and data given in the text and in tables 5.1 and 5.2, and evaluating a range of solar energy system sizes. We begin at zero and increment the collector area by the equivalent of one 4 x 8 ft collector (32 ft^2, 3 m^2). (A computer program was used to apply the model.)

The results are summarized in table 5.3 for selected collector areas ranging from 0 to 3328 ft^2 (309.2 m^2). The solution indicates a potential for only small present value net savings -- the largest net savings of $782 being realized from a system with a collector size of about 1248 ft^2 (115.9 m^2), supplying 37.8 percent of the energy requirements of the building. Based on the stated assumptions and data, substantially smaller or larger systems are shown to result in dollar losses.

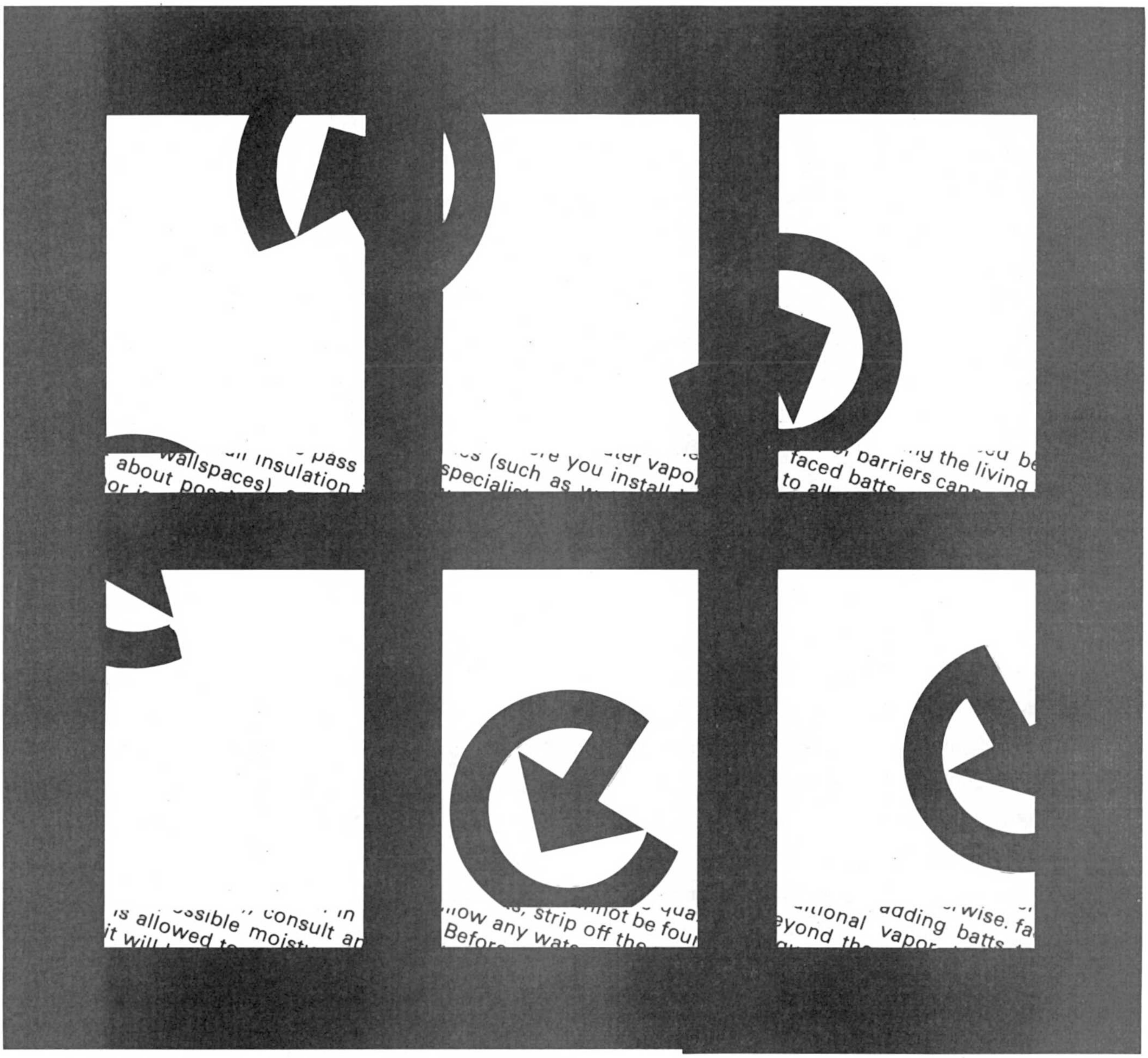
TABLE 5.3
ECONOMIC OPTIMIZATION OF A SOLAR ENERGY SYSTEM: ILLUSTRATION[a]

Collector area, ft² (m²) (1)	Fraction of load supplied by solar,[b] % (2)	PV solar acquisition cost, $ (3)	PV solar recurring costs, $ (4)	PV solar property tax, $ (5)	PV solar mortgage interest deductions, $ (6)	PV solar depreciation writeoff, $ (7)	PV solar system costs, $ (8)=(3)+(4)+(5)-(6)-(7)	PV energy costs, combined solar/conventional system, $ (9)	PV solar system costs plus energy costs of combined system, $ (10)=(8)+(9)	PV energy costs, conventional system only, $ (11)	After-tax PV net savings from solar, $ (12)=(11)-(10)
0 (0)	0	0	0	0	0	0	0	46,314	46,314	46,314	0
256 (23.8)	8.1	7,107	950	1,425	2,356	2,484	4,642	42,563	47,205	46,314	-891
512 (47.6)	16.2	11,882	1,588	2,382	3,940	4,152	7,760	38,811	46,571	46,314	-257
768 (71.3)	24.2	16,657	2,226	3,339	5,523	5,821	10,878	35,106	45,984	46,314	330
1,024 (95.1)	31.7	21,432	2,864	4,296	7,106	7,490	13,996	31,633	45,629	46,314	685
1,248* (115.9)	37.8	25,610	3,422	5,134	8,491	8,950	16,725	28,807	45,532	46,314	782*
1,536 (142.7)	45.0	30,982	4,140	6,211	10,272	10,827	20,234	25,473	45,707	46,314	607
2,048 (190.3)	56.1	40,532	5,417	8,128	13,439	14,165	26,473	20,332	46,805	46,314	-491
2,560 (237.8)	64.9	50,082	6,693	10,039	16,605	17,502	32,707	16,256	48,963	46,314	-2,649
3,328 (309.2)	74.7	64,408	8,607	12,911	21,355	22,508	42,063	11,717	53,780	46,314	-7,466

[a] Based on an example in Ruegg and Sav, Microeconomics of Solar Energy.

[b] The performance of the solar energy system is predicted using universal design and sizing curves described in U.S. Department of Energy, DoE Facilities Solar Design Handbook, DOE/AD-0006/1, U.S. Government Printing Office (Stock No. 061-000-00097-6), January, 1978.

NOTE: * denotes the optimal size for the solar energy system and its net savings ; "PV" abbreviates "present value."



6. Window Case Illustration

6.1 PROBLEM DESCRIPTION[1]

Another example of a design problem that bears on the energy consumption of a building is the inclusion of windows in the exterior envelope. The importance of windows to energy conservation is indicated by a recent study which estimated that windows may cause yearly

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[1] This illustration, including tables and figures, is taken from a more comprehensive analysis of window options reported by Rosalie T. Ruegg and Robert E. Chapman, in Economic Evaluation of Windows in Buildings: Methodology, National Bureau of Standards Building Science Series 119, April 1979.

energy costs to rise or fall by as much as 25 percent, compared with windowless walls, depending on their design, size, placement, accessories, and use.[1]

The purpose of this example is to show how the technique of life-cycle cost (LCC) analysis can be used in determining for a given building the most cost-effective windows from a set of alternative designs. The LCC procedure is outlined step by step, followed by the results of its application to several selected window systems in a typical residence[2] in Washington, D.C. Essentially the same model could be used for the analysis of other types of windows and buildings.

The major limitation to the use of the LCC model for evaluating windows is the difficulty of quantifying the benefits of natural ventilation, daylighting, and safety and psychological effects on occupants. Despite these limitations, the model is useful for guiding decisions about windows because it converts a number of different kinds of costs and benefits to a common dollar unit of measure that can be used for making comparisons.

6.2 STEP-BY-STEP APPROACH

In order to use economic analysis to improve the energy and cost effectiveness of windows, it is necessary to (1) identify the window alternatives that we wish to examine; (2) identify any constraints that we wish to impose, such as setting some minimum window size to satisfy building code requirements or to capture a scenic view; (3) specify the assumptions upon which the analysis will be based; (4) identify and assign values to costs and benefits of the various alternatives; (5) select a technique of economic analysis and develop it for its application to the problem at hand; and finally, (6) analyze the results and draw conclusions. Let us follow through these steps in the analysis of windows.

6.2.1 Identifying Window Alternatives

There are many specific window design strategies that can be undertaken to save energy.[3] Table 6.1 lists those options that we examine here.

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[1] Ibid., p. 2.

[2] The technical report from which this illustration is drawn also treats windows in commercial buildings.

[3] See S. Robert Hastings and Richard W. Crenshaw, Window Design Strategies to Conserve Energy, National Bureau of Standards Building Science Series 104, June 1977.

TABLE 6.1 WINDOW OPTIONS

Window Size	0, 12, 18, 30, 60 ft^2 (0, 1.1, 1.7, 2.8, 5.6 m^2)
Orientation	South, North, East, West
Glazing	Single, Double
Accessories	Insulating Shutters/Venetian Blinds
Daylighting	Substituted for Electric Lighting: Yes, No

The economic impacts of the various window options listed in table 6.1 will be examined and compared by assessing the life-cycle costs associated with (1) varying the area of the windows on the outside wall of the shaded area shown on figure 6.1 from 0 to 60 ft^2 (5.6 m^2); (2) varying the orientation of the windows by rotating the house 360°; (3) varying the glazing of the windows from single to double glazing, for each size and orientation; (4) equipping the windows with thermal shutters or venetian blinds versus leaving windows bare; and (5) turning off the electric lights whenever the natural daylight reaches a designated level.

6.2.2 Identifying Constraints

For the purpose of this example, it is assumed that there are no specific code requirements or other constraints that apply to the options to be examined.

6.2.3 Specifying Assumptions

Window options are to be examined for an 18' x 15' (5.5 m x 4.6 m) family room-kitchen as depicted in figure 6.1. Additional assumptions are presented in table 6.2.

6.2.4 Identifying the Costs and Benefits

Table 6.3 lists some potential costs and benefits commonly associated with windows. Ideally, one would assign a common unit of measure, such as dollars, to each item and find the solution which would maximize the net benefits associated with windows. However, despite some precedence for developing dollar measures for safety and psychological factors, it is difficult to develop measures that are broadly applicable to a diversity of situations and user reactions.

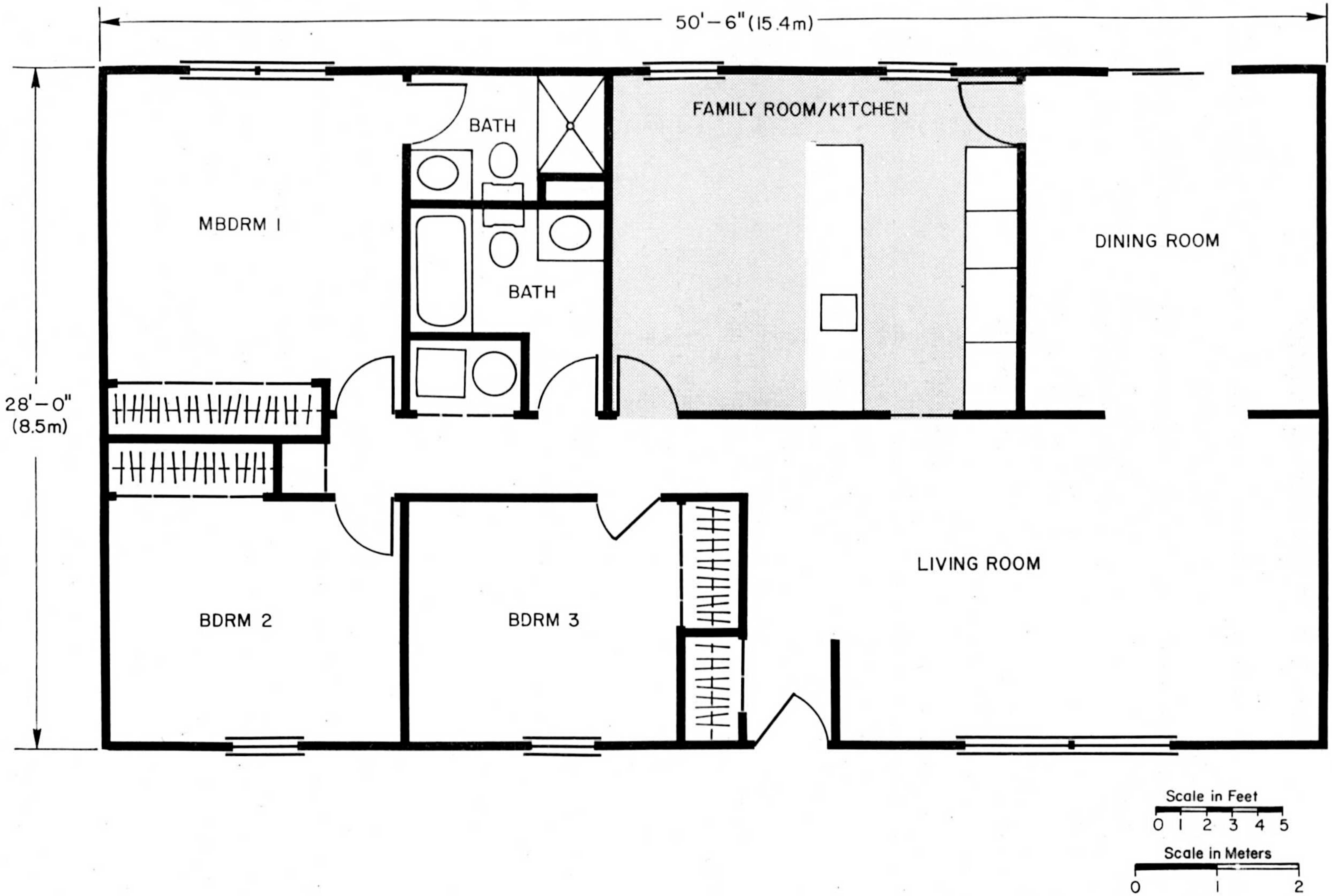

FIGURE 6.1 **Schematic Diagram of House with Shaded Study Module. (From Ruegg, Rosalie T. and Chapman, Robert E. *Economic Evaluation of Windows in Building: Methodology,* National Bureau of Standards Building Science Series 119, April 1979.)**

TABLE 6.2 WINDOW CASE ASSUMPTIONS[a]

CONSTRUCTION CHARACTERISTICS	SPECIFICATIONS	
Dimensions of Module[b]	18' wide x 15' long x 8' high	
Type of Construction	Block with brick veneer; 3 1/2" insul., U = 0.07	
Exterior Wall Area	144 ft^2	
Window Size	0, 12, 18, 30, 60 ft^2	
Window Construction	Wood; double hung; weatherstripped	
Building Life and Window Life	25 years or greater	
BUILDING LOADS[c]	**SPECIFICATIONS**	
Lights	0.65 watts/ft^2	
Equipment	0.52 watts/ft^2	
Air Leakage	0.5 air changes/hour	
Occupancy	0.5 persons	
Btu/person	260 Btu/hour/person	
Shading Coefficient	1.0 clear single glazed; 0.9 clear double glazed	
Thermal Storage Capacity	0.1	
SYSTEM EFFICIENCY	**SPECIFICATIONS**	
Gas Furnace Efficiency	0.65	
Cooling C.O.P.	2.0	
Electric Heating	1.0	
FUEL TYPE	**1977 PRICES**	
Electricity	3¢ per kWh	
Gas	30¢ per therm	
OPERATION	**CONDITIONS (night-time setting for 10 hours)**	
Thermostat Adjustment	72°F Winter day-time setting, 62°F winter night-time setting 78°F Summer day-time setting, 84°F summer night-time setting	
WINDOW MANAGEMENT	**WHEN USED**	
Thermal Shutters	Winter nights	
Venetian Blinds	Summer days	
GEOGRAPHIC LOCATION	**HEATING DEGREE DAYS[d]**	**SUMMER COOLING HOURS[e]**
Washington, D.C.	4,200	1,000

TABLE 6.2 CONT'D

ECONOMIC VARIABLES	ASSUMPTIONS[f]
Discount Rate	8% real
Energy Price Escalation	0% lower bound
Study Period	25 years

NOTE: Footnotes follow Table 6.2-M.

TABLE 6.2-M WINDOW CASE ASSUMPTIONS[a]

CONSTRUCTION CHARACTERISTICS	SPECIFICATIONS	
Dimensions of Module[b]	5.5 m wide x 4.6 m long x 2.4 m high	
Type of Construction	Block with brick veneer; 89 mm insul., U-metric = .40	
Exterior Wall Area	13.4 m^2	
Window Size	0, 1.1, 1.7, 2.8, 5.6 m^2	
Window Construction	Wood; double hung; weatherstripped	
Building Life and Window Life	25 years or greater	
BUILDING LOADS[c]	**SPECIFICATIONS**	
Lights	7.00 watts/m^2	
Equipment	5.60 watts/m^2	
Air Leakage	0.5 air changes/hour	
Occupancy	0.5 persons	
Btu/person	274 kJ/hour/person	
Shading Coefficient	1.0 clear single glazed; 0.9 clear double glazed	
Thermal Storage Capacity	0.1	
SYSTEM EFFICIENCY	**SPECIFICATIONS**	
Gas Furnace Efficiency	0.65	
Cooling C.O.P.	2.0	
Electric Heating	1.0	
FUEL TYPE	**1977 PRICES**	
Electricity	3¢ per kWh	
Gas	$2.84 per GJ	
OPERATION	**CONDITIONS (Night-time setting for 10 hours)**	
Thermostat Adjustment	40°C Winter day-time setting, 34.5°C winter night-time setting 43.5°C Summer day-time setting, 46.5°C summer night-time setting	
WINDOW MANAGEMENT	**WHEN USED**	
Thermal Shutter	Winter nights	
Venetian Blinds	Summer days	
GEOGRAPHIC LOCATION	**HEATING DEGREE DAYS[d]**	**SUMMER COOLING HOURS[e]**
Washington, D.C.	4,200	1,000

TABLE 6.2-M CONT'D

ECONOMIC VARIABLES	ASSUMPTIONS[f]
Discount Rate	8% real
Energy Price Escalation	0% lower bound
Study Period	25 years

[a] Only the windowed wall was considered to be exposed to the outdoors; all other surfaces of the room were considered to be adiabatic, that is, permitting no heat transfer.

[b] Due to the difficulty of modeling the thermal exchange between rooms, only a single room was modeled. Study of a single room within a larger house may not necessarily reflect the performance of the whole house.

[c] All loads are averaged over the 16 hour period from 7:00 AM to 11:00 PM.

[d] Heating degree day data, calculated from a base temperature of 65°F, was obtained from the ASHRAE Handbook of Fundamentals, 1972. The base value for "degree days" in SI units had not been established at the time of this study.

[e] Cooling hour data, calculated from a base temperature of 80°F, was obtained from Insulation Manual-Homes/Apartments (Rockville, MD: NAHB Research Foundation, Inc., September 1971), pp. 23-35. The base value for "cooling hours" in SI units had not been established at the time of this study.

[f] The report from which this example is drawn also evaluates life-cycle window costs based on an "upper bound" energy price escalation rate of 12% real, compounded annually.

TABLE 6.3 COSTS AND BENEFITS OF WINDOWS

COSTS	BENEFITS
*Purchase and Installation	*Desirable Winter Solar Heat Gain
*Maintenance, Repair, Insurance, and Taxes[a]	*Daylight
*Undesirable Heat Loss and Gain	Natural Ventilation
Safety Hazard	Higher Occupant Productivity
Noise and Visual Distractions	Occupant Sense of Well-Being
Undesirable Light, Glare, and Contrast	Enhanced Interior and Exterior Appearance
Loss of Privacy	Source of Information to Occupant
Limitations on Furniture Arrangement	Emergency Egress and Access

*Items quantified in the LCC model.

[a] Insurance and taxes are included in the model and are taken into account for commercial buildings in the report from which this example is taken; for owner-occupied residential buildings, however, insurance and tax effects related to windows appear relatively trivial in amount and, hence, are not included in the cost data for this example.

A more practical approach -- taken in this case example -- is to include in the economic evaluation model those costs and benefits whose effects can be measured in dollars with a reasonable degree of confidence: purchase and installation costs of windows and accessories, maintenance and repair costs, value of thermal gains and losses, insurance, taxes, and, with somewhat less confidence, energy savings through daylighting. A major omission from the case study assessment of thermal benefits is natural ventilation, which has been excluded due to limitations of the thermal analysis model used in the analysis. Although the resulting economic measure of window performance is incomplete, it can be used as a basis against which the estimates of the value of the other effects can be compared. For example, the value of a better view associated with a large window can be weighed subjectively against the specific additional cost that is estimated for a larger window versus a smaller or no window.

The next requirement is to assign dollar values to costs and benefits. In this case example, costs of purchasing and installing the windows are considered to be the excess of providing an area of window versus the costs of an equivalent area of wall. This approach to cost estimation is appropriate for making window design decisions for a new building. Estimated costs for windows of the type given in table 6.2, for the Washington, D.C. area, are shown in table 6.4. Table 6.5 gives estimates of the costs of the window accessories that were selected for study, also for Washington, D.C. Table 6.6 gives estimates of maintenance and repair costs, first for 1977, and then in present value dollars for the 25-year life cycle.

Figures 6.2 and 6.3 show the estimated energy costs for the room in question, for the year 1977, for two cases: (1) when the windows are left bare, are not used for daylighting, and the room thermostat is not adjusted for energy conservation; and (2) when the windows are accessorized with venetian blinds and shutters, are used for daylighting, and the room thermostat is adjusted for energy conservation.[1] Room energy costs are shown initially for the windowless room (at the point of intercept with the vertical axis). Each figure shows the energy costs for both single and double-glazed windows. For simplicity, only the costs associated with southern and northern exposures are shown.

Figure 6.2 indicates that when windows are bare and are not used for daylighting, estimated yearly energy costs increase for both northern and southern exposures as the size of the window increases.

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[1] The energy cost data plotted in figures 6.2 and 6.3 are based on the thermal analysis model and the energy consumption estimates derived from applying that model reported by T. Kusuda and B. Collins in Simplified Analysis of Thermal and Lighting Characteristics of Windows: Two Case Studies, National Bureau of Standards BSS 109, February 1978.

TABLE 6.4 WINDOW PURCHASE AND INSTALLATION COSTS IN EXCESS OF THE COST OF A NON-WINDOWED WALL

COMPONENT	1977 DOLLAR COSTS BY WINDOW AREA			
	12 ft^2 (1.1 m^2)	18 ft^2 (1.7 m^2)	30 ft^2 (2.8 m^2)	60 ft^2 (5.6 m^2)
Windows[a]				
Single Glazed	52.50	70.70	122.55	245.10
Double Glazed	81.80	109.36	192.61	385.23
Wall[b]	33.72	50.58	84.30	168.60
Window Cost Less Wall Cost[c]				
Single Glazed	18.78	20.12	38.25	76.50
Double Glazed	48.08	58.78	108.31	216.63

[a] These costs are based on 1977 list retail prices for good-quality wood, double-hung windows, reduced 10 percent to reflect a typical builder's discount. They were provided by a distributor in the Washington, D.C. area. The designated window areas are provided by single or multiple units of the windows described above. In some cases, the available window sizes do not provide the exact area designated; however, the differences are very small. The 12 ft^2 (1.1 m^2) area is provided by a 3' x 3'11" (0.9 m x 1.2 m) window; the 18 ft^2 (1.7 m^2) area by a 3' x 6' (0.9 m x 1.8 m) window; the 30 ft^2 (2.8 m^2) by two 3' x 5' (0.9 m x 1.5 m) windows; and the 60 ft^2 (5.6 m^2) by four 3' x 5' (0.9 m x 1.5 m) windows. Based on the recommendation of a home builder in the Washington, D.C. area, an installation cost of $5.00 per window or pair of windows is added to the adjusted list price to obtain the total estimated cost of purchase and installation.

[b] Costs of non-windowed wall areas corresponding in size to the windowed areas are based on a price of $2.81/$ft^2$ ($30.25/$m^2$) as estimated by a home builder in the Washington, D.C. area. The wall section is assumed to be face brick veneer over 8" (203 mm) concrete block with building paper sheathing, 3 1/2" (89 mm) of insulation, and 1/2" (13 mm) of painted interior drywall.

[c] The additional costs incurred for windowed areas of the building are the difference between the costs of windows and the costs of walls for the same wall area.

TABLE 6.5 COST OF WINDOW ACCESSORIES

TYPE OF ACCESSORY	1977 DOLLAR COST BY WINDOW AREA			
	12 ft^2 (1.1 m^2)	18 ft^2 (1.7 m^2)	30 ft^2 (2.8 m^2)	60 ft^2 (5.6 m^2)
Venetian Blinds[a]	17	20	36	72
Solid Wooden Shutters[b]	42	51	96	192

[a] Prices shown are averages of 1977 prices quoted by several low-to-moderately priced department stores.

[b] Estimates are those of a Washington area building contractor for constructing, installing, and finishing solid, tightly-fitted wooden shutters. (Prices quoted by custom drapery shops in the area were considerably higher.)

TABLE 6.6 WINDOW MAINTENANCE AND REPAIR COSTS

TYPE OF MAINTENANCE AND REPAIR	DOLLAR COSTS BY WINDOW AREA			
	12 ft^2 (1.1 m^2)	18 ft^2 (1.7 m^2)	30 ft^2 (2.8 m^2)	60 ft^2 (5.6 m^2)
CLEANING COSTS				
Annual Cleaning Cost for 1977[a]	1.20	1.80	3.00	6.00
Present Value Dollar Cost over 25 years[b]	13.00	19.00	32.00	64.00
SCRAPING, RECAULKING, AND REPAINTING EVERY 5th YEAR AT $1.50/$ft^2$ ($16.15/$m^2$)				
Recurring Cost Every 5th Year in 1977 Dollars[c]	18.00	27.00	45.00	90.00
Present Value Dollar Cost Over 25 Years[d]	30.00	45.00	75.00	151.00

[a] Based on a rate of $0.10/$ft^2$ ($1.08/$m^2$).

[b] Based on annually recurring costs in constant 1977 dollars discounted with an 8 percent discount rate and rounded to the nearest dollar.

[c] Based on a rate of $1.50/$ft^2$ ($16.15/$m^2$) in 1977 dollars.

[d] Based on recurring costs every 5th year in constant 1977 dollars discounted with an 8 percent discount rate and rounded to the nearest dollar.

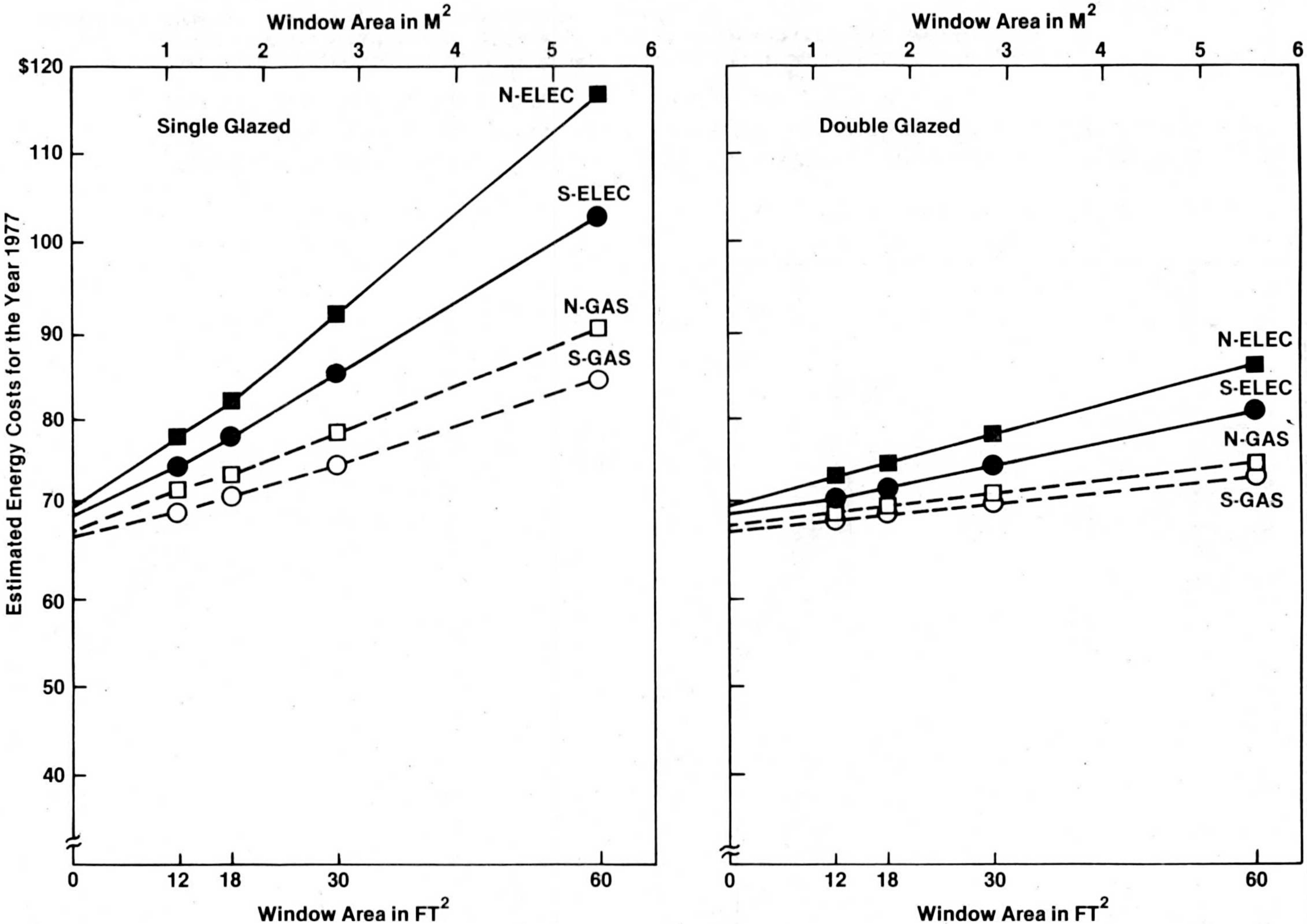

FIGURE 6.2 Estimated Room Energy Costs for the Year 1977, in Washington, D.C., with North (N) or South (S) Facing Windows and Gas or Electric (ELEC) Heat: Analysis of Internal and External Thermal Loads Only.[a]

[a]Based on seasonal heating and cooling requirements estimated for a wall U value of 0.07 and a storage load factor of 0.1, as reported in Tamani Kusuda and Belinda L. Collins, *Simplified Analysis of Thermal and Lighting Characteristics of Windows: Two Case Studies*, National Bureau of Standards Building Science Series 109, February 1978, Figure 12, p. 47.

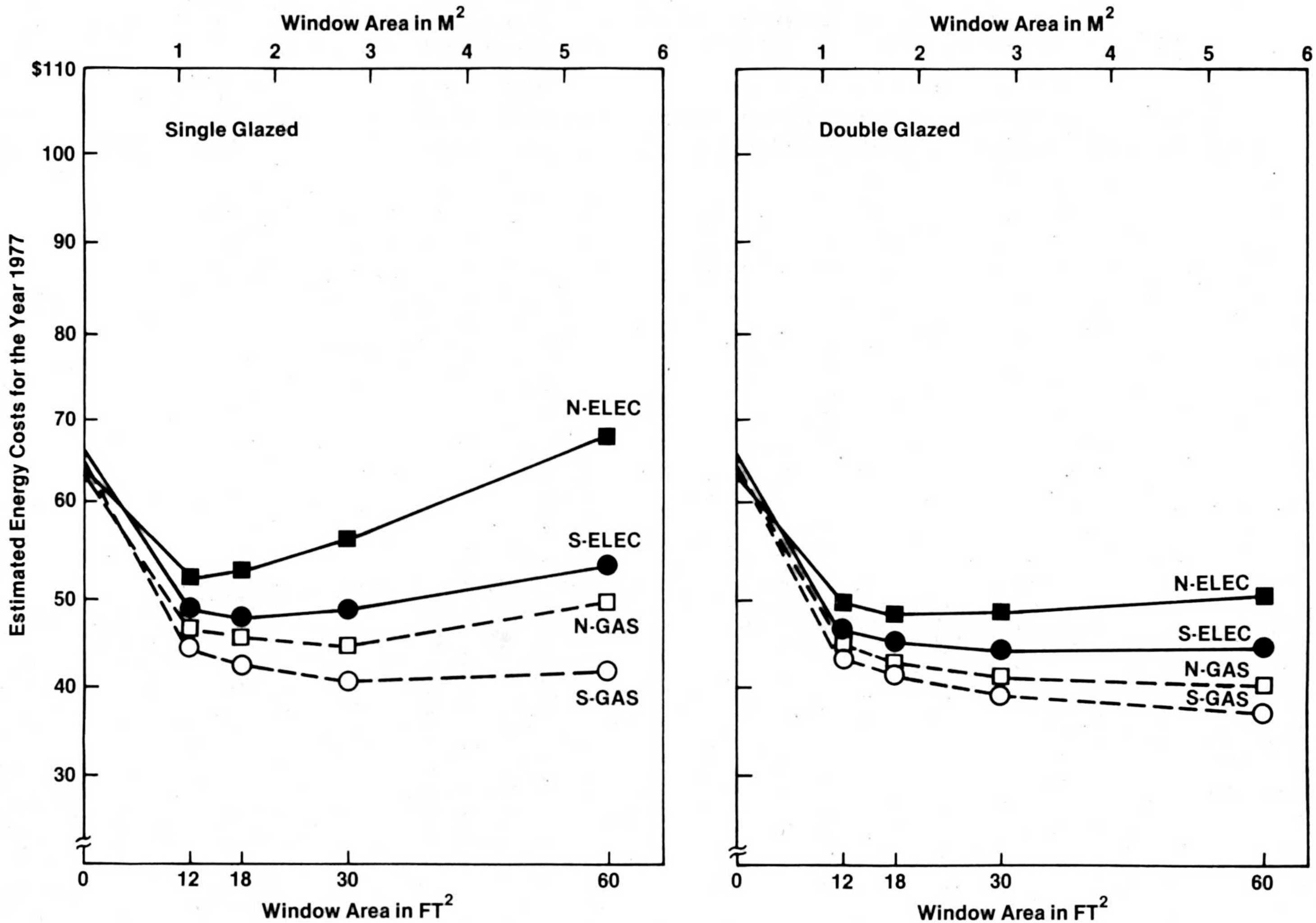

FIGURE 6.3 Estimated Room Energy Costs for the Year 1977, in Washington, D.C., with North (N) or South (S) Facing Windows and Gas or Electric (ELEC) Heat: Analysis of Internal and External Loads, with Window Accessories, Thermostat Adjustment, and Daylighting.[a]

[a]Based on seasonal heating and cooling requirements estimated for a wall U value of 0.07 and a storage load factor of 0.1, as reported in Tamani Kusuda and Belinda L. Collins, *Simplified Analysis of Thermal and Lighting Characteristics of Windows: Two Case Studies,* National Bureau of Standards Building Science Series 109, February 1978, Figure 15, p. 50.

The provision of winter thermal storage capacity, together with greater summer shading--the customary practice in passive solar energy design--could substantially improve the cost effectiveness of the bare south-facing windows.[1]

Under the assumed conditions, figure 6.3 shows that when the accessories are used and daylighting is substituted for electric lighting, energy costs initially decline with increasing window area. Although the chief effect of daylighting is to reduce electric lighting costs, there are two additional effects. By reducing the heat generated from electric lighting, daylighting is estimated to increase heating costs for the gas furnace; it also decreases electric cooling costs--the larger of these two effects.

6.2.5 Selecting a Technique of Evaluation

The life-cycle costing technique was selected to treat this problem because the technique is suitable for assessing the net impact of the various window alternatives on building and energy costs, regardless of whether they raise or lower costs. The total life-cycle costs of purchasing, installing, maintaining, and repairing each window alternative, as well as the energy costs of the room with each window alternative, are calculated. The life-cycle costs of heating, cooling, and lighting the windowless room are also calculated to provide a basis for comparison.[2] The results of the model provide useful information not only for new construction where all options examined may be open, but also for existing buildings where options are limited. Where windows are estimated to raise life-cycle costs, the extra costs can be traded against expected benefits not easily measured in dollars, such as the view. Where windows are estimated to lower life-cycle costs, the designer may wish to include more, rather than fewer windows.

The life-cycle cost model is described algebraically as follows:

Energy Costs

$$LCC_{PV} = [E_H C_H + E_C C_C + E_{LE} C_{LE}]\ UPW^*\ T(1)\ +$$

Purchase and Installation

$$[PW + IW - ACW + ACC[PB_A + IB_A + PS_A + IS_A]]\ T(2)\ +$$

Maintenance, Repair, and Insurance

$$[M_A UPW + M_{HA} UPW^{\pm} + INS_A UPW]\ T(1)$$

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[1] For a description of the use of windows in passive solar energy systems, see Edward Mazria, The Passive Solar Energy Book (Emmaus, PA: Rodale Press, 1979).

[2] The life-cycle costs of the windowless room include, in addition to the energy costs of the room, estimates of the costs of a section of wall in place of the windows.

where,

LCC_{PV} = the present value over the life cycle of the acquisition, maintenance, repair, and insurance costs for the window and its accessories, plus the energy costs for the room with windows.

E_H, E_C, E_{LE} = the quantities of energy required for heating, cooling, and lighting equipment.

C_H, C_C, C_{LE} = the current prices per unit of the energy sources used for heating, cooling, and lighting equipment.

UPW* = the uniform present value factor adjusted for future escalation in energy prices.

$$UPW^* = \sum_{t=1}^{N} \left(\frac{1 + FPE}{1 + DIS} \right)^t ,$$

where N = the life cycle over which the costs of windows are examined.

FPE = the energy price escalation rate.

DIS = the discount rate.

T(1) = the proportion of operating expenses remaining after taxes. For residential case applications T(1) = 1.

PW = the purchase price of the window.

IW = the installation cost of the windows.

A = the area of the window in square feet (or m^2).

CW = the cost per square foot (or per m^2) for the exterior wall.

ACC = 1 if management accessories are used; 0 otherwise.

PB_A = the purchase price of venetian blinds of area A.

IB_A = the installation cost of venetian blinds of area A.

PS_A = the purchase price of a thermal shutter of area A.

IS_A = the installation cost of a thermal shutter of area A.

T(2) = a factor which adjusts for the present value of capital depreciation. allowances from taxable income.

M_A = the annual cleaning cost for a window of area A.

UPW = the uniform present worth factor.

M_{HA} = the fifth year's repainting and recaulking costs for a window area A.

UPW† = the uniform present worth factor modified for once-in-five-years costs.

INS_A = the annual insurance cost for a window of area A, less reimbursables, plus non-reimbursables to cover total costs associated with both incurring and avoiding damages.

The model incorporates the acquisition, maintenance, and repair costs of the window alternatives, as well as the present and future prices of energy, the efficiency of the mechanical heating, cooling, and lighting systems, the cost of money, and the life expectancy of the window and building. It is adaptable to either a residential or nonresidential analysis. (To apply the model, a computer program is helpful.)

6.2.6 Analysis and Conclusions

For each window option, the appropriate cost elements described above are used in the life-cycle model. Table 6.7 presents results for Washington, D.C., based on the assumptions employed in this case example. Following are some conclusions that can be drawn from these results:

When Windows are Bare and Not Used for Daylighting

1. Without thermal storage capacity and summer shading of windows, the larger the window, the larger the life-cycle cost. (Table 6.7, cols. 2-5.)
2. From the standpoint of those costs examined, windows are more economical if they are located on the south side than on the north side of a building (Cols. 2 versus 4, and 3 versus 5).
3. If fuel prices were to remain about constant, double glazing would be cost effective for northern exposures, particularly for larger windows, but not for south-facing windows (Cols. 2 versus 3, 4 versus 5)[1].

When Windows are Equipped with Venetian Blinds and Shutters That are Appropriately Managed and Used for Daylighting

1. The life-cycle costs of the room can be reduced by adding a window. (Cols. 6-9)
2. Life-cycle costs tend to be lowest if a small, single-glazed window is added on the south side. (Col. 6 versus cols. 7 through 9)
3. Double glazing would tend not to pay if energy prices were to remain about constant. (Cols. 6 versus 7 and 8 versus 9)
4. The energy savings from the managed accessories and from using the windows for daylighting more than compensate for the costs of the accessories and the loss of winter heat from electric lighting. (Cols. 2 through 5 versus cols. 6 through 9.) (Additional results not shown here indicate that escalating fuel prices make windows appear more

[1] Additional results not shown here indicate that rapidly escalating fuel prices cause double glazing to be cost effective for both north and south-facing windows (Rosalie T. Ruegg, and Robert E. Chapman, Economic Evaluation of Windows in Buildings: Methodology).

TABLE 6.7 LIFE-CYCLE COSTS, IN PRESENT VALUE DOLLARS, FOR ALTERNATIVE WINDOW SIZES, ORIENTATIONS, GLAZINGS, ACCESSORIES, AND USE: WASHINGTON, D.C. CASE EXAMPLE[a]

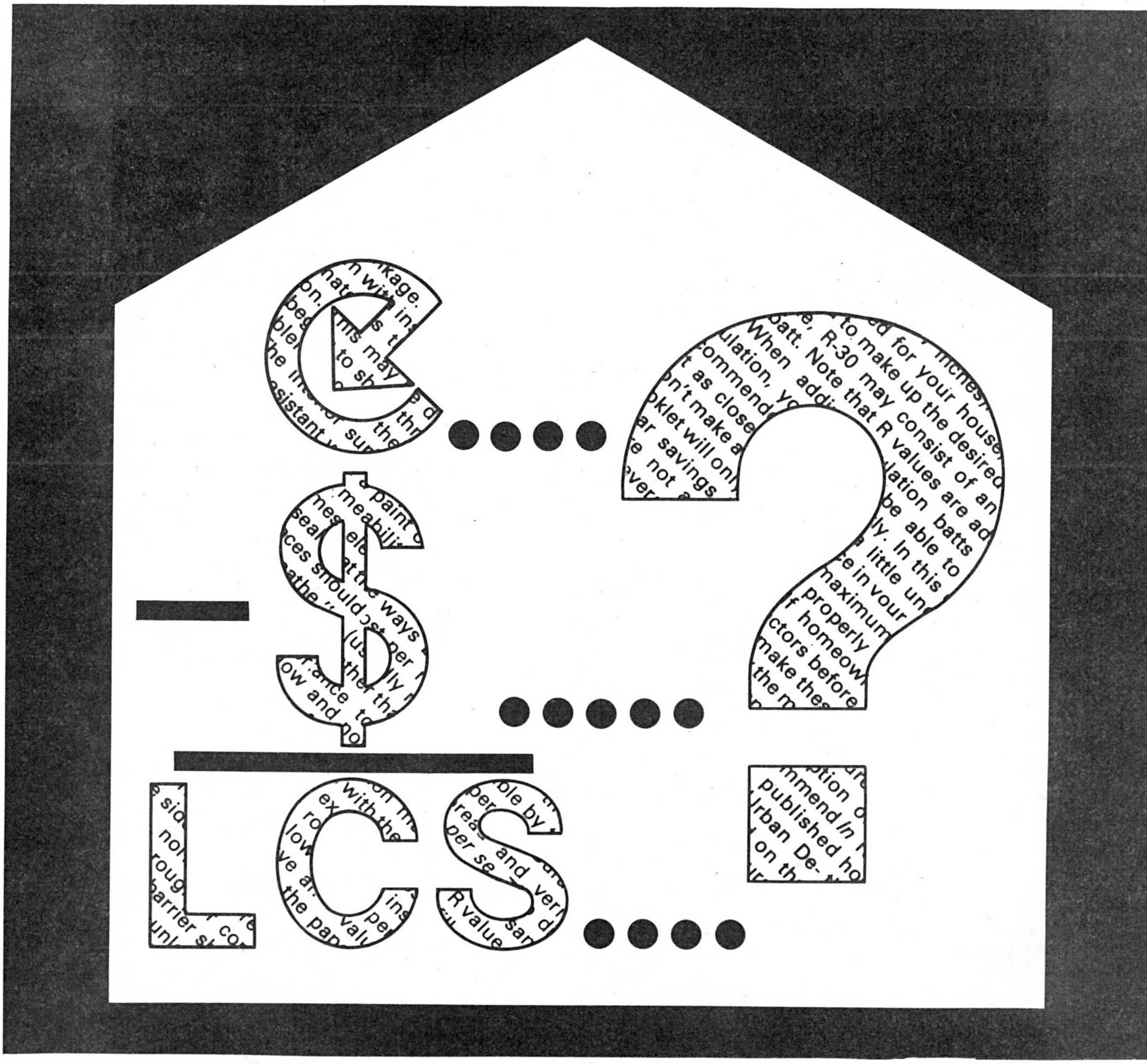
Window Size ft^2 (m^2) (1)	Bare Windows Without Daylighting				Windows Equipped with Venetian Blinds and Shutters, Managed, Used for Daylighting[b]			
	South		North		South		North	
	Single (2)	Double (3)	Single (4)	Double (5)	Single (6)	Double (7)	Single (8)	Double (9)
0 (0)	719	719	718	718	695	695	693	693
12 (1.1)	808	820	824	824	606	630	625	640
18 (1.7)	849	857	870	865	621	652	649	664
30 (2.8)	944	963	980	975	738	738	780	809
60 (5.6)	1187	1214	1260	1234	1054	1153	1135	1185

[a] "Use" refers to whether available daylighting from the windows is taken advantage of in order to reduce the cost of electric lighting, and whether the blinds and shutters are appropriately "managed."

[b] The added assumption of night-time adjustments to the thermostat reduces costs for this case for all window areas examined, as well as for the windowless wall. Hence, the first row shows a difference between the two cases in their present value costs even when no window is used.

NOTE: These results are based on constant energy prices. For rapidly increasing energy prices, the life-cycle costs of the bare windows rise considerably more than shown above, and the life-cycle costs of the managed windows fall more and over a wider range of window sizes than is shown above. Thus, the potential for savings through window design and management is considerably greater than is indicated by these selected data for the stable energy price "lower bounds" scenario.

desirable from a cost standpoint when they are used effectively for daylighting. Rising energy prices also cause double glazing to be more economical than single glazing for most window sizes and orientations.)



7. Sample Problems in Evaluating Energy Conservation and Solar Energy Investments

This section provides 15 problems and their step-by-step solutions. The problems and solutions are presented in increasing order of difficulty, starting with simple discounting exercises and ending with comprehensive analyses of more complex investments. The title of each section describes what aspect of investment analysis is emphasized in that problem, so that the reader can work the problem set selectively. To ensure that the reader has a complete understanding of the techniques used in this report, however, it is recommended that all the problems be worked, and in the order presented.

(The problems may be solved using the discount factor tables in Appendix C. Final results are rounded to the nearest dollar, unless otherwise stated. Although problems are defined in both customary U.S. and metric units, step-by-step solutions are worked out in customary U.S. units only.

7.1 FINDING THE PRESENT VALUE OF A REPLACEMENT COST

Problem

What is the present value of a replacement cost (R) of $5,000 that will occur at the end of 10 years if the discount rate is 10%?

Solution

Find the Single Present Worth Factor (SPW) for 10 years and a 10% discount rate in table C-3, column 3. This value is 0.3855. Multiply the replacement cost by this factor to obtain the present value of the replacement cost:

$$R = (0.3855)\ (\$5,000) = \$1,928.$$

7.2 FINDING THE PRESENT VALUE OF AN ANNUAL MAINTENANCE COST

Problem

What is the present value of a yearly routine maintenance cost (M) of $2,000 over 20 years if the discount rate is 10%?

Solution

To find the present value maintenance cost, obtain the Uniform Present Worth Factor (UPW) from table C-3, column 7, and multiply by the maintenance cost:

$$M = (8.514)\ (\$2,000) = \$17,028.$$

7.3 FINDING THE PRESENT VALUE OF ENERGY SAVINGS

Problem

What is the before-tax present value of electricity savings (ES) over 25 years for a commercial-type building if the annual savings evaluated in today's dollars are \$600, the price of electricity is escalating at a rate of 1%, compounded annually, and the discount rate is 10%?

Solution

To find present-value energy savings, obtain the Modified Uniform Present Worth Factor (UPW*) for a 10% discount rate, a 1% escalation rate and 25 years from table D-2 and multiply by the base-year energy savings:

$$ES = (9.8919)\ (\$600) = \$5{,}935.$$

7.4 FINDING THE ANNUAL VALUE OF A REPLACEMENT COST

Problem

What is the annual value equivalent of a replacement cost (R_A) of \$2,500 expected to occur in 10 years, assuming a discount rate of 10%?

Solution

To find the annual value of the replacement cost, first obtain the Single Present Worth Factor (SPW) from table C-3, column 3, and multiply by the future replacement cost to find the present value equivalent:

$$R_{PV} = (0.3855)\ (\$2{,}500) = \$963.75$$

Next find the Uniform Capital Recovery Factor (UCR) from table C-3, column 5, and multiply by the present value of the replacement cost to find its annual value:

$$R_A = (0.1628)\ (\$963.75) = \$157.$$

Or, alternatively, obtain the Uniform Sinking Fund Factor (USF) from table C-3, column 4, and multiply by the future replacement cost:

$$R_A = (0.06275)\ (\$2,500) = \$157.$$

7.5 FINDING THE NET SAVINGS FROM A FURNACE RENOVATION

Problem

What will be the net present value savings (NS), before taxes, of renovating the furnace in an industrial plant if the investment costs are \$50,000 and the annual savings are 2×10^9 Btu (2.1 TJ) of distillate fuel for 15 years? Assume the discount rate is 10%, today's price of distillate is \$4.47 per 10^6 Btu, (4.24 per GJ) and the price of distillate is increasing at a rate of 4% compounded annually.

Solution

To find the value of a year's worth of savings at today's prices (ES_B), multiply the annual quantity of energy saved by today's price:

$$ES_B = (\$4.47/10^6\ \text{Btu})\ (2,000 \times 10^6\ \text{Btu}) = \$8,940.$$

To obtain the present value of the fuel savings over 15 years (ES_{PV}), multiply the annual fuel savings at today's prices by the Modified Uniform Present Worth Factor (UPW*) for a 4% escalation rate, a 15-year period, and a 10% discount rate, from table D-2:

$$ES_{PV} = (9.8604)\ (\$8,940) = \$88,151.98$$

To find the net present value savings (NS) from the investment, subtract the investment costs, already in present value dollars, from the present value energy savings:

$$NS = \$88,151.98 - \$50,000 = \$38,152.$$

7.6 FINDING THE UPPER LIMIT ON INVESTMENT COSTS FOR A HEAT PUMP

Problem

What is the maximum investment cost (i.e., the "break-even" cost per house) that could be incurred for the following energy conservation project in order to avoid a net loss.

The proposed project is to replace the existing electric resistance HVAC systems with heat pumps in a group of similar houses on a military base. With the electric resistance system, the yearly electrical cost per house averages $2,000 at today's prices. The yearly electrical cost is estimated to be half as much with the heat pump. Additional assumptions are as follows: (a) the existing electric resistance system has no salvage value when replaced; (b) the maintenance and repair costs of the heat pump are identical to those of the existing system; (c) the remaining life of the existing system (if not replaced), the life of the heat pump, and the life of the house are all estimated to be 25 years; (d) the discount rate is 10%; and (e) the price of electricity is projected to escalate at a rate of 2% compounded annually over the 25 years.

Solution

The break-even (BE) investment cost is the cost that is equal to the present value savings. Therefore, find the break-even cost by calculating the present value of energy savings. To do this, first obtain from table D-2 the Modified Uniform Present Worth Factor (UPW*) for a 10% discount rate, a 2% escalation rate, and 25 years, and then multiply it by the annual energy savings at today's prices:

$$BE = (10.8193)\ (\$2{,}000 - \$1{,}000) = \$10{,}819.$$

7.7 DETERMINING THE COST EFFECTIVENESS OF ATTIC INSULATION

Problem

A homeowner proposes to add additional insulation to his attic in order to save on his gas bill. With the new insulation he expects to conserve 30×10^6 Btu (32 GJ) per year. The cost of insulating his attic is \$675. The estimated remaining life of the house is 10 years, and the discount rate is 10%. Assume that today's price of natural gas is \$2.75/10^6 Btu (\$2.61/GJ) and the price is projected to escalate over the next 10 years at a rate of 5% compounded annually. Is it cost effective to add the additional insulation? What would be the net savings or losses (NS)?

Solution

To determine cost effectiveness of the additional insulation, first find the value of a year's energy savings (ES_Y) at today's prices:

$$ES_Y = (\$2.75/10^6 \text{ Btu})\ (30 \times 10^6 \text{ Btu}) = \$82.50$$

Next estimate the present value of the energy savings (ES_{PV}) by obtaining the Modified Uniform Present Worth Factor (UPW*) from table D-2, for a 10% discount rate, a 5% escalation rate, and 10 years, and then multiplying this factor by the annual energy savings at today's prices:

$$ES_{PV} = (7.8118)\ (\$82.50) = \$647.77$$

Now find net savings by subtracting the cost of insulation (already in present value dollars) from present value energy savings:

$$NS = \$644.47 - \$675 = -\$31.$$

The additional insulation is not cost effective based on the assumed present and future prices of natural gas.

7.8 FINDING THE TOTAL LIFE-CYCLE COST OF AN OIL HEATING SYSTEM

Problem

The existing oil heating system in a public building is estimated to require a partial replacement every 10 years costing \$2,000 in constant dollars in order to keep it functional. The annual operation and maintenance (O&M) costs of this system are \$500 in constant dollars. The annual energy requirement is 2 x 10^9 Btu (2.1 TJ) of oil. The expected remaining life of the building is 25 years. The heating system is estimated to have no salvage value, net of disposal costs, if removed from the building. What is the total life-cycle cost (TLCC) in present value dollars of retaining this heating system over the remaining life of the building, assuming a real discount rate of 10%, a price of distillate oil today of \$5.35/10^6 Btu (\$5.07/GJ), and an escalation rate in the price of oil 5%, compounded annually, faster than the price of general price inflation?

Solution

To find the TLCC of retaining the existing system, calculate the present value of each cost component and sum them. First, find the present value of replacement costs by obtaining the Single Present Worth Factors (SPW) for 10 and 20 years from table C-3, column 3, and multiplying each by the corresponding replacement cost. Sum the present value amounts to find the total present value of replacement costs (R_{PV}):

$$R_{PV} = (0.3855)(\$2,000) + (0.1486)(\$2,000) = \$1,068.20.$$

Second, find the present value of annual O&M costs (OM_{PV}) by obtaining the Uniform Present Worth Factor (UPW) from table C-3, column 7, and multiplying it by the annual O&M costs:

$$OM_{PV} = (9.077)(\$500) = \$4,538.50.$$

Next, find the present value of fuel costs (FC_{PV}) by multiplying today's price of distillate by the annual quantity of energy, and then also multiplying by the Modified Uniform Present Worth Factor (UPW*) from table D-2 for a 10% discount rate, a 5% escalation rate, and 25 years:

$$FC_{PV} = (\$5.35/10^6 \text{ Btu})(2,000 \times 10^6 \text{ Btu})(14.4367) = \$154,472.69.$$

Finally, sum the present value of replacement, O&M, and fuel costs:

$$TLCC = (\$1{,}068.20 + (\$4{,}538.50) + (\$154{,}472.69) = \$160{,}079.$$

7.9 DETERMINING THE COST EFFECTIVENESS OF A SOLAR ENERGY SYSTEM

Problem

Would it be cost effective to add the following solar energy system to the building whose existing heating system is evaluated in section 7.8? Assume that the proposed solar energy system would reduce the energy requirements of the oil system from 2×10^9 Btu to 1.75×10^9 Btu (2.1 TJ to 2.85 TJ) per year. The initial investment cost is $10,000 and the annual O&M costs of the solar energy system are $100 in constant dollars. Assume that the existing system is used in combination with the solar energy system to meet the remaining energy requirements and that the maintenance and replacement costs of the existing system remain the same.

Solution

The cost effectiveness of the proposed solar energy system can be determined by comparing the TLCC of the heating-related components of the building with the solar energy system, to the TLCC without the solar energy system as calculated in the solution of section 7.8. It is necessary to include the O&M and replacement costs of the existing oil furnace in the TLCC of the solar alternative, even though they are assumed to be unaffected by the addition of the solar energy system, because they were included in the TLCC solution to problem 7.8.

The initial investment cost (I) is already in present value dollars:

$$I = \$10{,}000.$$

The present value of replacement costs (R_{PV}) is the same as was calculated in section 7.8.

$$R_{PV} = \$1{,}068.$$

The annual O&M costs are raised by $100 to a total of $600. To find the present value of the O&M costs (OM_{PV}), obtain the Uniform Present Worth Factor (UPW) from table C-3, column 7, and multiply it by the annual O&M costs:

$$OM_{PV} = (9.077)\ (\$600) = \$5{,}446.20.$$

To find the present value of fuel costs (FC_{PV}) for that part of the heating load not met by the solar energy system, multiply today's price of distillate by the remaining annual quantity required for the oil furnace, and then also multiply by the Modified Uniform Present Worth Factor (UPW) from table D-2 for a 10% discount rate, a 5% escalation rate, and 25 years:

$$FC_{PV} = (\$5.35/10^6 \text{ Btu})\ (1{,}750 \times 10^6 \text{ Btu})\ (14.4367) = \$135{,}163.60.$$

Finally, to find the TLCC of the heating-related components of the building with the solar energy system installed, sum the initial investment cost and the present values of replacement, O&M, and fuel costs:

$$\text{TLCC} = \$1{,}068.20 + \$5{,}446.20 + \$135{,}163.60 + \$10{,}000 = \$151{,}678.$$

Because the TLCC of the heating system with solar ($151,678) is less than the TLCC without solar ($160,079), the solar energy system would be a profitable investment.

(It should be noted, however, that solar energy systems of other designs and sizes might be more cost effective than the one evaluated, and furthermore, that investments in energy conservation to reduce the heating requirements of the building might be more cost effective than meeting part of the existing load with solar energy; that is, the solution to this problem is not necessarily indicative of the least-cost approach to heating the building, although it does show an improvement over the existing situation.)

7.10 FINDING THE INTERNAL RATE OF RETURN ON AN INVESTMENT IN EXHAUST STACK RECUPERATORS

Problem

What would be the internal rate of return (before-taxes) on an investment in exhaust stack recuperators for retrofit to batch furnaces in an industrial plant if each of the recuperators costs $10,000 to purchase and install, will last 10 years, and will result in annual fuel savings of $3,000 each year in constant dollars?

Solution

To calculate the internal rate of return (IRR) on the $10,000 investment, calculate the net savings (NS) for trial values of the discount rate (i) used in the appropriate discounting formula until a value of i is found which will equate present value cost and savings and thereby result in a zero value for NS.

$$NS = [\$3,000\ (UPW,\ i = ?,\ 10\ years)] - \$10,000 = 0.$$

If NS is positive, the IRR is higher than the trial rate, and a higher value of i should then be tried in the equation. If NS is negative, the IRR is lower than the trial rate, and a lower value of i should be tried.

Based on visual inspection of the costs and savings, a discount rate of 25 percent might be tried to solve the above equation:[1]

$$NS_{i=25\%} = [\$3,000\ (3.571)] - \$10,000 = \$713.$$

Since NS is positive for i = 25%, try a higher value of i, say, i = 30%:

$$NS_{i=30\%} = [\$3,000\ (3.092)] - \$10,000 = -\$724.$$

Since NS is negative for i = 30%, but positive for 25%, the IRR on this investment lies between 25% and 30%.

At this point, rather than repeat the calculations for values of i between 25% and 30%, simple proportional interpolation may be used to solve for the approximate value of i which results in a zero NS:

$$i = 0.25 + \left(\frac{\$713}{\$1437} \times .05 \right) = 0.275.^{a}$$

[a] Rounded to the nearest thousandth

Hence, the IRR on this investment (before taxes) is approximately 27.5 percent.

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[1] Discount rates above 20% are not given in this handbook, but such rates can be found in engineering economics textbooks.

7.11 FINDING THE DISCOUNTED PAYBACK ON A WASTE HEAT RECOVERY SYSTEM

Problem

What is the expected time to discounted payback (before taxes and without financing) for an investment in a waste heat recovery system for an industrial plant under the following conditions: (1) the waste heat recovery system costs $250,000 to purchase and install; (2) the "waste heat" recovered can be distributed to meet the entire space heating load of 3×10^9 Btu (3.2 TJ) for a large area of adjoining office space that is currently met by an existing oil-fired boiler with a technical efficiency of 0.5; (3) today's price of the oil used in the boiler is $\$6.50/10^6$ Btu ($6.16/GJ) and it is expected to escalate at a compound annual rate that is 6% faster than the rate of general price inflation over 30 years; (4) if continued to be used as the sole heating system, the boiler will require both an immediate renovation costing $20,000 and annual O&M costs of $2,000 (in constant dollars); (5) the existing system will have no salvage value, net of disposal costs, if it is replaced now or later; (6) the waste heat recovery system will require a major replacement costing $60,000 (in constant dollars) at the end of 15 years; (7) the waste heat recovery system will have a salvage value estimated at $15,000 (in constant dollars) at the end of 30 years; (8) both the existing boiler renovated and the new waste heat recovery system are expected to last over the remaining life of the building, estimated at 30 years; and (9) the investor's opportunity cost (before taxes and without inflation) is 12 percent.

Solution

Sum the discounted savings year-by-year, less any discounted non-initial investment costs, until the accumulated amount is just sufficient to pay back the additional initial investment cost associated with the waste heat system as is shown in table 7.11.1.

Payback is estimated to occur early in the eighth year since cumulative savings by the end of the seventh year are nearly sufficient to offset the initial investment cost. (Note that this measure does not incorporate any savings and costs after the eighth year and, hence, provides only a rough, partial measure of cost effectiveness.)

TABLE 7.11.1 CALCULATING TIME TO PAYBACK FOR THE WASTE HEAT RECOVERY SYSTEM

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Year	Cumulative PV Energy Savings, $[a]	Cumulative PV O&M Savings, $[b]	Cumulative PV Replacement Costs, $[c]	Cumulative Savings Less Non-initial Investment Costs, $ (5) = (2) + (3) - (4)	Additional Initial Investment Cost, $[d]	Cumulative Savings Less Non-initial Investment Costs Minus Additional Initial Investment Cost, $ (7) = (5) - (6)
1	36,909.60	1,786.00	0	38,695.60	230,000	-191,304
2	71,845.80	3,380.00	0	75,225.80		-154,774
3	104,906.10	4,804.00	0	109,710.10		-120,290
4	136,195.80	6,074.00	0	142,269.80		- 87,730
5	165,812.40	7,210.00	0	173,022.40		- 56,978
6	193,837.80	8,222.00	0	202,059.80		- 27,940
7	220,365.60	9,128.00	0	229,493.60		- 506
8[e]	245,469.90	9,936.00	0	255,405.90		25,406

[a] Calculated as $\frac{3{,}000 \times 10^6 \text{ Btu}}{.5}$. (6.50/10^6 Btu) . (UPW*), where i = 12%, e = 6%, and n = number years over which annual energy savings are to be cumulated.

The UPW* factors can be calculated from the UPW* formula in Appendix B or found in Appendix table D-3.

[b] Calculated as ($2,000) · (UPW), where i = 12% and n = number of years over which annual savings are to be cumulated.

The UPW factor can be calculated from the UPW formula in Appendix B or found in Appendix table C-4.

[c] Calculated as ($60,000) · (SPW), where i = 12% and n = 15. Since payback occurs before the 15th year, this calculation is not shown in the table.

The SPW factor can be calculated from the SPW formula in Appendix B or found in Appendix table C-4.

[d] The waste heat recovery system costs $250,000 to purchase and install. The existing system requires an immediate renovation outlay of $20,000. Hence, the additional initial investment cost incurred by selecting the waste heat recovery system instead of keeping the existing system is the difference between $250,000 and $20,000, or $230,000.

[e] Payback time.

Problem

An energy conserving building design is being considered as an alternative to a conventional building design for a State office building.

Which is the least-cost design over the life cycle under the following conditions?

The two designs are approximately equivalent in total assignable and auxiliary spaces and in functional performance with respect to the purpose of the building. Each has two underground levels for parking and seven office floors, plus a mechanical house. The approximate gross size of the building for each design is 176,000 ft^2 (16 350.9 m^2).

The two designs differ primarily in the envelope, building configuration, orientation, and lighting system. The energy conserving design is slightly elongated on the east-west axis for greater exposure of the south side to solar radiation. Its window area is 25% of the wall area, as opposed to 40% in the conventional building, and most of that 25% is located on the south side. More massive exterior surfaces are used and insulation is increased, reducing the wall U value from 0.16 to 0.06 (U-metric from 0.91 to 0.34), and the roof U value from 0.15 to 0.06 (U-metric from 0.85 to 0.34). Horizontal window fins reduce the cooling load of the energy conserving design. The north wall of the first floor of the energy conserving design is earth bermed. It is assumed that both designs will last at least the 25-year time horizon of the government agency, and, for lack of any good basis for projecting differences in their salvage values, they are both assumed to have no salvage value at the end of the 25-year study period. A discount rate of 10% is assumed.

Following is a listing of the major relevant costs for each design:

(a) Site Acquisition Costs: To ensure adequate exposure of south-facing windows, an additional cost of $100,000 is necessary for the energy conserving design.

(b) Architectural and Engineering Design Fees and Construction Costs:

Energy Conserving Design	Conventional Design
$9,780,000	$9,380,000

(c) Annual Energy Consumption, Fuel Costs, and Escalation Rates:

Today's Fuel Costs	Projected Escalation Rates	Annual Energy Consumption for the Energy Conserving Design	Annual Energy Consumption for the Conventional Design
Natural Gas:			
$\$3.21/10^6$ Btu	4%	2.290×10^9 Btu	4.980×10^9 Btu
($3.04/GJ)		(2.416 TJ)	(5.254 TJ)
Electricity:			
$\$14.24/10^6$ Btu	2%	3.886×10^9 Btu	7.277×10^9 Btu
($13.50/GJ)		(5.000 TJ)	(7.678 TJ)

(d) Non-fuel O&M Costs

	Energy Conserving Design	Conventional Design
Recurring Annual Costs:	$70,000	$90,000
Repairs to External Surfaces every 10 years:	$60,000	$100,000

Solution

To solve this problem, calculate the estimated TLCC of each of the designs being considered and choose the design with the lowest TLCC; or, alternatively, calculate the NS, SIR, and IRR based on the additional costs and the energy savings associated with the energy conservation design, and choose the energy conservation design if it is estimated to result in a positive NS, an SIR > 1, or an IRR > the State's minimum acceptable rate of return on State projects. The following solution is based on the TLCC approach, where we compute and sum the present value of each of the cost components for each design alternative. Tables 7.12.1 through 7.12.5 treat the conventional design and tables 7.12.6 through 7.12.10, the energy conserving design.

TABLE 7.12.1 FUEL COSTS OF CONVENTIONAL DESIGN

(1) Fuel Type	(2) Today's Price Per 10^6 Btu	(3) Annual Energy Consumption	(4) UPW*[a] Factor	(5) Present Value of Fuel Costs (2) x (3) x (4)
Electricity	$14.24	7,277 x 10^6 Btu	10.8193	$1,121,144.34
Natural Gas	$ 3.21	4,980 x 10^6 Btu	13.0686	$ 208,912.03
		Total Present Value Fuel Costs		$1,330,056.37

[a] UPW* Factors are based on a 10% discount rate, a 2% escalation rate for electricity, a 4% escalation rate for natural gas, and 25 years, from table D-2.

TABLE 7.12.2 RECURRING O&M COSTS

(1) Annual O&M Cost in Today's Dollars	(2) UPW[a] Factor	(3) PV of Recurring O&M Costs (1) x (2)
$90,000	9.077	$816,930.00

[a] UPW Factor is based on a 10% real discount rate and 25 years, from table C-3, column 7.

TABLE 7.12.3 NON-RECURRING O&M COSTS

(1) Year in Which Cost Occurs	(2) Amount	(3) SPW[a] Factor	(4) PV of Non-Recurring O&M Costs (2) x (3)
10	$100,000	0.3855	$38,550.00
20	$100,000	0.1486	$14,860.00
	Total Present Value Non-Recurring O&M Costs		$53,410.00

[a] SPW Factors are based on a 10% discount rate and 10 and 20 years, from table C-3, column 3.

TABLE 7.12.4 INVESTMENT COSTS

(1) Building Costs	(2) Additional Costs	(3) PV of Total Investment Costs (1) + (2)
$9,380,000	0	$9,380,000.00

TABLE 7.12.5 TOTAL LIFE-CYCLE COST OF CONVENTIONAL DESIGN

(1) PV of Fuel Costs	(2) PV Recurring O&M	(3) PV Non-Recurring O&M	(4) PV Investment Costs	(5) Total Life- Cycle Cost (1) + (2) + (3) + (4)
$1,330,056.37	$816,930.00	$53,410.00	$9,380,000.00	$11,580,396

TABLE 7.12.6 FUEL COSTS OF ENERGY CONSERVING DESIGN

(1) Fuel Type	(2) Today's Price Per 10^6 Btu	(3) Annual Energy Consumption	(4) UPW*[a] Factor	(5) Present Value of Fuel Costs (2) x (3) x (4)
Electricity	$14.24	3,886 x 10^6 Btu	10.8193	$598,703.71
Natural Gas	$ 3.21	2,290 x 10^6 Btu	13.0686	$ 96,065.97
		Total Present Value Fuel Costs		$694,769.68

[a] UPW* Factors are based on a 10% discount rate, a 2% escalation rate for electricity, a 4% escalation rate for natural gas, and 25 years, from table D-2.

TABLE 7.12.7 RECURRING O&M COSTS

(1) Annual O&M Cost in Today's Dollars	(2) UPW[a] Factor	(3) PV of Recurring O&M Costs (1) x (2)
$70,000	9.077	$635,390.00

[a] UPW Factor is based on a 10% discount rate and 25 years, from table C-3, column 7.

TABLE 7.12.8 NON-RECURRING O&M COSTS

(1) Year in Which Cost Occurs	(2) Amount	(3) SPW[a] Factor	(4) PV of Non-Recurring O&M Costs (2) x (3)
10	$60,000	0.3855	$23,130.00
20	$60,000	0.1486	$ 8,916.00
	Total Present Value Non-Recurring O&M Costs		$32,046.00

[a] SPW Factors are based on a 10% discount rate and years 10 and 20, from table C-3, column 2.

TABLE 7.12.9 INVESTMENT COSTS

(1)	(2)	(3)
Building Costs	Additional Costs	PV of Total Investment Costs (1) + (2)
$9,780,000	$100,000 (Site Acquisition Cost)	$9,880,000.00

TABLE 7.12.10 TOTAL LIFE-CYCLE COST OF ENERGY CONSERVING DESIGN

(1)	(2)	(3)	(4)	(5)
PV of Fuel Costs	PV Recurring O&M	PV Non-Recurring O&M	PV Investment Costs	Total Life-Cycle Cost (1) + (2) + (3) + (4)
$694,769.68	$635,390.00	$32,046.00	$9,880,000.00	$11,242,206

In conclusion, the energy conserving design is estimated to be cost effective because its total life-cycle cost is $338 thousand less than that of the conventional design. The difference in the totals of overall life-cycle building costs for the two designs is, however, small in terms of TLCC; in fact, it might be argued that when dealing with amounts of this magnitude, errors in cost estimating could easily exceed the difference in the TLCC figures. It should be recognized, however, that the focus of this design problem is a relatively small segment of the total costs of the two designs: that is, the costs of special energy conserving features and the resulting cost avoidances. Considered in this light, the energy conserving design is more clearly the cost-effective choice because a cost avoidance of over $800 thousand is estimated to result from the additional expenditure of $500 thousand, producing a net savings of over $300 thousand and a savings-to-investment ratio of 1.68.

7.13 SIZING A SOLOR ENERGY SYSTEM FOR THE SOLAR IN FEDERAL BUILDINGS DEMONSTRATION PROGRAM[1]

Problem

A 3-story Federal Office building in Arizona is to be retrofitted with a solar energy system for space heating and service hot water as a special project to demonstrate the use of solar energy. Given the following energy requirements, existing systems, solar energy system size options, costs, and performance data, determine which solar energy system size will maximize net savings or minimize net losses (whichever is applicable) over a 25 year period. The annual space heating load of the building is 200×10^6 Btu (211 GJ), and the annual hot water load is 55×10^6 Btu (58 GJ). The existing space heating system is a distillate oil-fired furnace with a technical efficiency of 0.65.

The mid-1980 price of distillate oil to the Federal agency occupying the building is $\$5.92/10^6$ Btu (\$5.61/GJ), and the energy evaluation is to be based on price projections of the U.S. Department of Energy's Energy Information Administration (EIA). The projected escalations of distillate oil prices (in excess of general price inflation) are 0.87 percent from mid-1980 through mid-1985, 3.63 percent from mid-1985 through mid-1990, and 2.35 percent thereafter.[2] The UPW* Factor for distillate for commercial buildings based on the above escalation rates for a 25 year life and a 10 percent discount rate is 10.86.[3]

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[1] The Solar in Federal Buildings Program was created under the auspices of the National Energy Act as a major initiative to demonstrate the Federal government's leadership in promoting the use of renewable resources in its own buildings. Federal agencies submitting solar project proposals under this program are required to provide life-cycle cost analyses of the proposed projects using the life-cycle procedures, assumptions, and data given in Subpart A, 10 CFR, Part 436, as published in the Federal Register. ["Federal Energy Management and Planning Program; Methodology and Procedures for Life-Cycle Cost Analyses," Federal Register (Rules and Regulations), Vol. 45, No. 16, Wednesday, January 23, 1980.] The necessary data for solving this problem according to the Federal life-cycle costing procedure are provided in the text above.

[2] Ibid., tables C-2 and C-6 through C-8.

[3] Ibid., table B-9.

The existing hot water system is an electric resistance water heater, assumed to be 100 percent efficient after the point of delivery to the building.

The mid-1980 price of electricity to the Federal agency occupying the building is $15.09/10^6 Btu ($14.30/GJ), and the EIA-projected rates of escalation in electricity prices (in excess of general price inflation) in this location are 1.86 percent from mid-1980 through mid-1985, -0.84 percent from mid-1985 through mid-1990, and -0.79 percent after mid-1990.[1] The UPW* Factor for electricity for commercial buildings based on the above escalation rates for a 25 year life and a 10 percent discount rate is 9.45.[2]

Both existing systems -- the oil-fired furnace and the electric hot water system -- will be retained as backup systems to the solar energy system, and for simplicity, are assumed to have the same non-fuel O&M and replacement costs whether used alone or as solar backup systems, as well as the same technical efficiency. Again for simplicity, the existing furnace and water heating system, the solar energy system of various sizes, and the building are all expected to last for 25 years.

Investment costs for the solar energy system consist of the sum of a "fixed" cost of $15,000 and a "variable" cost of $7.00/ft^2 ($75.35/m^2) of collector area, including labor and materials.[3]

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[1] _Ibid._, tables C-2 and C-6 through C-8.

[2] _Ibid._, table B-9.

[3] To determine the economically efficient size of an investment, it is critical to know approximately how total costs change as system size is increased. A part of the costs of the various elements of the system will tend to be relatively insensitive to size changes in the system beyond some minimum size, and hence are often referred to as "fixed" or invariant costs. For example, even a small system may require piping, ducting, storage, and controls whose costs may not change much as the system size is increased over some range. Because they are not sensitive to size changes, fixed costs are not a determinant in economically efficient sizing, apart from comprising a cost "hurdle" over which the savings of a system of any size must rise to achieve cost effectiveness. While few costs are truly "fixed" over a wide range of investment sizes, many may tend to be somewhat fixed over a small range of sizes. (Continued on next page.)

Annual O&M costs for the solar energy system are estimated in constant dollars as 2 percent of the initial investment cost of the solar energy system.

The solar energy system sizes and the estimated technical performance of each size, stated in terms of the fractions of the annual loads to be met by solar, are shown in table 7.13.1.[1]

TABLE 7.13.1 SOLAR ENERGY SYSTEM SIZE AND PERFORMANCE DATA

Alternate system sizes ft^2	(m^2)	Solar Fraction (F) of Annual Space Heating Load, %	Solar Fraction (F) of Annual Hot Water Load, %
500	(46.5)	40	50
1,000	(92.9)	65	75
1,500	(139.4)	82	90

The evaluation is to be carried out with mid-1980 as the present and with a 10% real discount rate.

(Footnote 3 continued from previous page)
"Variable" costs are those elements of costs that are significantly sensitive to size changes, and, hence, a prime determinant of the size that maximizes net savings or minimizes net losses. Variable costs include costs associated with storage and other components of the system other than collector area; however, the convention of expressing all variable costs in terms of collector area is followed for convenience.

[1] Solar performance data are required to carry out the economic evaluation. For a description of several solar performance models, see Byon Winn, "Active System Design/Sizing," Solar Design Workbook, Solar Federal Buildings Program, Draft 2, August 1979, Chapter 12.

Solution

As a basis of comparison, begin by calculating the relevant life-cycle costs of continuing to operate the existing systems.

Existing Systems

Assuming the existing systems have no net salvage value if disposed of now, there is no cost equivalent to an investment cost of continuing to operate these systems.

Since the non-fuel O&M and replacement costs of the existing systems are assumed to be the same whether the systems are used alone or as auxiliaries to the solar energy system, these costs would cancel out of the cost equations, and therefore can be ignored in the evaluation.

Hence, only the present value of the fuel costs of the existing systems need be calculated to provide a basis for evaluating the relative cost effectiveness of the solar energy systems:

TABLE 7.13.2 PRESENT VALUE OF ENERGY COSTS WITH THE EXISTING SYSTEMS ONLY

(1) Energy Type	(2) Load	(3) System Efficiency	(4) Annual Energy Consumption (4)=(2)÷(3)	(5) Today's Energy Price, $\$/10^6$ Btu	(6) UPW* Factor	(7) PV Energy Costs, \$ (7)=(4)x(5)x(6)
Distillate Oil	200×10^6 Btu	0.65	307.69×10^6 Btu	5.92	10.86	19,781.76
Electricity	55×10^6 Btu	1.00	55.00×10^6 Btu	15.09	9.45	7,843.03
			Total PV Energy Costs			27,624.79

Solar Energy Systems

To evaluate the relevant life-cycle costs of each of the solar energy systems of the sizes being considered, calculate and sum for each size the present values of investment costs, O&M costs, and fuel costs of the auxiliary systems.

A. System Size = 500 ft^2

TABLE 7.13.3 PRESENT VALUE OF AUXILIARY ENERGY COSTS FOR 500 FT^2 SOLAR ENERGY SYSTEM

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Energy Type	Annual Energy Consumption Without Solar	Annual Solar Fraction (F)	Annual Energy Consumption of Auxiliary Systems (4)=(2)x [1 - (3)]	Today's Energy Price, $\$/10^6$ Btu	UPW* Factor	PV Energy Costs for Auxiliary Systems, $ (7) = (4) x (5) x (6)
Distillate Oil	307.69×10^6 Btu	0.40	184.61×10^6 Btu	5.92	10.86	11,868.80
Electricity	55.00×10^6 Btu	0.50	27.50×10^6 Btu	15.09	9.45	3,921.51
		Total PV Energy Costs, Auxiliary Systems				15,790.31

TABLE 7.13.4 INITIAL SOLAR INVESTMENT COST FOR 500 FT^2 SYSTEM

(1) Fixed Costs, \$	(2) Variable Costs, \$/ft^2	(3) Collector Size, ft^2	(4) Total Initial Investment Costs, \$ (4) = (1) + [(2) x (3)]
15,000	7.00	500	18,500.00

TABLE 7.13.5 PRESENT VALUE OF SOLAR O&M COSTS FOR 500 FT^2 SYSTEM

(1) Annual O&M as a Fraction of Initial Investment Cost	(2) Initial Investment Cost, \$	(3) UPW Factor	(4) PV O&M Costs, \$ (4) = (1) x (2) x (3)
0.02	18,500.00	9.077	3,358.49

TABLE 7.13.6 PRESENT VALUE TLCC FOR 500 FT^2 SYSTEM

(1) Total PV Auxiliary Energy Costs, \$	(2) Initial Solar Investment Costs, \$	(3) PV Solar O&M Costs, \$	(4) Solar TLCC (4) = (1) + (2) + (3)
15,790.31	18,500.00	3,358.49	37,648.80

TABLE 7.13.7 PRESENT VALUE NET SAVINGS OF 500 FT^2 SYSTEM

(1) PV Energy Costs With Existing Systems, $	(2) Solar TLCC for 500 ft^2 System, $	(3) NS of 500 ft^2 System, $ (3) = (1) - (2)
27,624.79	37,648.80	-10,024

Having determined that the 500 ft^2 solar energy system results in estimated net losses of $10,024 over the 25-year life cycle, move on to evaluate the next size, 1,000 ft^2, using the same procedure but changing the solar fraction and the collector area as indicated.

B. System Size = 1,000 ft^2

TABLE 7.13.8 PRESENT VALUE OF AUXILIARY ENERGY COSTS FOR 1,000 FT^2 SOLAR ENERGY SYSTEM

(1) Energy Type	(2) Annual Energy Consumption Without Solar	(3) Annual Solar Fraction (F)	(4) Annual Energy Consumption of Auxiliary Systems (4) = (2) x [1 - (3)]	(5) Today's Energy Price $/$10^6$ Btu	(6) UPW* Factor	(7) PV Energy Costs for Auxiliary Systems, $ (7) = (4) x (5) x (6)
Distillate Oil	307.69 x 10^6 Btu	0.65	107.69 x 10^6 Btu	5.92	10.86	6,923.52
Electricity	55.00 x 10^6 Btu	0.75	13.75 x 10^6 Btu	15.09	9.45	1,960.76
			Total PV Energy Costs, Auxiliary Systems			8,884.28

TABLE 7.13.9 INITIAL SOLAR INVESTMENT COST FOR 1,000 FT^2 SYSTEM

(1)	(2)	(3)	(4)
Fixed Costs, $	Variable Costs, $/$ft^2$	Collector Size, ft^2	Total Initial Investment Costs, $ (4) = (1) + [(2) x (3)]
15,000	7.00	1,000	22,000.00

TABLE 7.13.10 PRESENT VALUE OF SOLAR O&M COSTS FOR 1,000 FT^2 SYSTEM

(1)	(2)	(3)	(4)
Annual O&M as a Fraction of Initial Investment Cost	Initial Investment Cost, $	UPW Factor	PV O&M Costs, $ (4) = (1) x (2) x (3)
0.02	22,000.00	9.077	3,993.88

TABLE 7.13.11 PRESENT VALUE TLCC FOR 1,000 FT^2 SYSTEM

(1) Total PV Auxiliary Energy Costs, $	(2) Initial Solar Investment Costs, $	(3) PV Solar O&M Costs, $	(4) Solar TLCC (4) = (1) + (2) + (3)
8,884.28	22,000.00	3,993.88	34,878.16

TABLE 7.13.12 PRESENT VALUE NET SAVINGS OF 1,000 FT^2 SYSTEM

(1) PV Energy Costs With Existing Systems, $	(2) Solar TLCC for 1,000 ft^2 System, $	(3) NS of 1,000 ft^2 System, $ (3) = (1) - (2)
27,624.79	34,878.16	-7,253

hile the 1,000 ft^2 solar energy system also results in estimated net losses, the losses are ower by $2,771 as compared with the smaller system examined. Complete the sizing problem y evaluating the costs of the 1,500 ft^2 system.

C. System Size = 1,500 ft^2

epeat the identical procedure used to evaluate the 500 ft^2 and the 1,000 ft^2 systems, ıanging only the collector area and the annual solar fraction, to find the following otal life-cycle costs and net savings for the 1,500 ft^2 system.

TABLE 7.13.13 PRESENT VALUE TLCC FOR 1500 FT^2 SYSTEM

(1) Total PV uxiliary Energy osts, $	(2) Initial Solar Investment Costs, $	(3) PV Solar O&M Costs, $	(4) Solar TLCC (4) = (1) + (2) + (3)
,345.02	25,500.00	4,629.27	34,474.29

TABLE 7.13.14 PRESENT VALUE NET SAVINGS OF 1,500 FT^2 SYSTEM

(1) PV Energy Costs With Existing Systems, $	(2) Solar TLCC for 1,500 ft^2 System, $	(3) NS of 1,500 ft^2 System, $ (3) = (1) - (2)
27,624.79	34,474.29	-6,850

mparing the TLCC of the four alternatives in table 7.13.15, it may be concluded that it re cost effective to continue to operate the existing systems without the solar invest- However, if a solar energy system is to be added, the largest system size considered 0 ft^2) is estimated to result in the lowest net losses over the 25-year life cycle.

TABLE 7.13.15 TLCC SUMMARY FOR ALTERNATIVES EXAMINED

(1) TLCC of Existing Systems Used Alone, $	(2) TLCC of 500 ft^2 Solar Energy System Plus Auxiliary Fuel, $	(3) TLCC of 1,000 ft^2 Solar Energy System Plus Auxiliary Fuel, $	(4) TLCC of 1,500 ft^2 Solar Energy System Plus Auxiliary Fuel, $
27,625	37,649	34,878	34,474

7.14 Planning a Residential Energy Conservation Package for Maximum Net Savings

Problem

Plan an energy conservation package that will maximize net savings to the owner/occupant of the house described below, given the following conditions and candidate retrofit projects. Also calculate estimated net savings in present value dollars from the "package" of projects selected.

The house has been weatherstripped and caulked. It has R-11 insulation in the attic, as well as all the insulation that can be accommodated in the floors and walls without making major structural modifications. A jacket has been added to the domestic water heater, thermal draperies have been added to the windows, and the family is practicing energy conservation in using lighting, appliances, and nighttime set-back of the thermostat during the heating season.

The house is currently heated by an electric resistance system that is in good condition and could reasonably be expected to last over the remaining life of the house with only negligible maintenance and repair. The efficiency of the system is assumed to be 100 percent.

The annual space heating load is 83 x 10^6 Btu (88 GJ). The owners now pay $16.89 per 10^6 Btu ($16.01/GJ) of electricity and expect that price to escalate at an average annual compound rate of 9 percent, including inflation, over the next 15 years. The house does not have an air conditioning system.

The annual domestic hot water load is 22 x 10^6 Btu (23 GJ). It is currently supplied by an electric water heater. The efficiency of the existing hot water system is assumed to be 100 percent.

The owners expect to occupy the house for at least another 15 years, and would like to base their energy conservation investment decisions on a 15-year time horizon, neglecting possible resale effects at the end of that time. They have a limited budget of $1,500 to spend on the house and would like to obtain the largest possible return on their conservation budget. Their best alternative return on the $1,500 is 8 percent from tax-exempt municipal bonds.

The following options are being considered for retrofit to the house:

(A) Addition of a solar domestic water heater. The system that has been recommended as reliable and sufficiently durable to last the 15 years without major maintenance or repair, costs $1,500, and is expected to meet 80 percent of the annual hot water load.

(B) Replacement of the existing electric resistance space heating system with a relatively high efficiency (0.7 efficiency) gas furnace. The replacement of the existing system with the gas furnace will cost $1,000. No net salvage value is expected from disposal of the existing system. The gas furnace is expected to have about the same maintenance and repair costs and life expectancy as the existing system. The price of gas is now $4.70 per 10^6 Btu ($4.45/GJ) and is expected to escalate at an average annual compound rate of 10 percent, including inflation, over the next 15 years.

(C) Addition of attic insulation to raise the current resistance (R) level from R-11 to R-19. The insulation will cost $225 to purchase and install and is expected to reduce the energy consumption for space heating by 12 percent.

(D) Conditional on Alternative (C), the addition of attic insulation to raise the R value from R-19 to R-30. Increasing insulation from R-19 to R-30 will cost $100 and is expected to reduce energy consumption by 5 percent of the heating costs at R-19.[1]

(E) Conditional on Alternatives (C) and (D), the addition of attic insulation to raise the R value from R-30 to R-38. This will cost $75 more than raising the value to R-30 and is expected to save 2 percent of the heating cost at R-30.

(F) Replacement of from one to five existing north-facing single-glazed windows with double-glazed windows. Each window will cost $200 and each is expected to reduce the energy consumption for space heating by 2 percent, for a total of 10 percent if all five are replaced.[2]

(G) Addition of from one to five storm windows to north-facing windows (instead of replacing the windows as described in (F)) and/or the addition of up to three storm windows to east-facing windows. The storm windows will cost $50 each. They are expected to reduce the energy consumption for space heating by 9 percent if all five of the north-facing windows are retrofitted, or 1.8 percent per north-facing window. They are expected to reduce the energy consumption by 0.7 percent per east-facing window, for a total reduction of 2.1 percent if storm windows are added to all three of the east-facing windows.

In evaluating the alternatives, assume there are no available grants or tax credits and that property taxes are not expected to be affected by the retrofit investments.

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[1] It is assumed that all increases in insulation would be made during the same visit from the contractor. Therefore, the fixed costs which were incorporated into the cost of Alternative (C) do not apply to the R-30 and R-38 applications.

[2] Interdependencies between shell modifications (i.e., wall insulation and windows) are not treated here. Slight changes in actual energy savings might be expected from one of these modifications depending on whether the other one was undertaken.

Solution

Compute the present value (PV) of costs, savings and net savings (NS), and the savings-to-investment ratio (SIR) for each alternative, taking into account where necessary the interdependencies between those investments that improve the shell of the house and those that affect the heating system. Rank projects in descending order of their SIR's until the budget is exhausted. Then sum the net savings of those projects selected.

Begin by evaluating each candidate project as follows:

(A) Addition of a Solar Domestic Water Heater

PV Cost = \$1,500

	Annual Electricity for Water Heating		Solar Fraction		Today's Price of Electricity		UPW*, d=8%, e=9%, n=15 years		
PV Savings =	$\frac{22 \times 10^6 \text{ Btu}}{1}$	x	0.80	x	$16.89/10^6 Btu	x	16.1606	=	$4,803.96

where UPW* is taken from Appendix table D-1.

$$NS = \$4{,}803.96 - \$1{,}500 = \$3{,}303.96$$

$$SIR = \frac{\$4{,}803.96}{\$1{,}500} = 3.20$$

(B) Replacement of Existing Space Heating System with Gas Furnace

PV Cost = \$1,000

	Annual Quantity of Electricity		Today's Price of Electricity		UPW*, d=8%, e=9%, n=15
PV Savings =	[$\frac{83 \times 10^6 \text{ Btu}}{1}$	x	$16.89/10^6 Btu	x	16.1606]

Annual Quantity of Gas		Today's Price of Gas		UPW*, d=8%, e=10%, n=15
[$- \frac{83 \times 10^6 \text{ Btu}}{.7}$	x	$4.70/10^6 Btu	x	17.4264]

= \$22,655.06 - \$9,711.48 = \$12,943.58

NS = \$12,943.58 - \$1,000 = \$11,943.58

$$SIR = \frac{\$12,943.58}{\$1,000} = 12.94$$

<u>(C) Addition of Attic Insulation, R-11 to R-19</u>

(C-1) With Existing Electric Space Heating System

PV Cost = \$225

PV Space Heating % Reduction

PV Savings = \$22,655.06 x 0.12 = \$2,718.61

NS = \$2,718.61 - \$225 = \$2,493.61

$$SIR = \frac{\$2,718.61}{\$225} = 12.08$$

(C-2) With Replacement of Existing System with Gas Furnace

PV Cost = \$225

PV Space Heating % Reduction

PV Savings = \$9,711.48 x 0.12 = \$1,165.38

NS = \$1,165.38 - \$225 = \$940.38

$$SIR = \frac{\$1,165.38}{\$225} = 5.18$$

(D) Addition of Attic Insulation, R-19 to R-30

Alternative (D) is conditional on Alternative (C) being undertaken. It can be evaluated in terms of the incremental costs and savings over and above those associated with raising the R value from R-11 to R-19.

(D-1) With Existing Electric Space Heating System

PV Cost = $100

	PV Space Heating	After R-19		% Reduction	
PV Savings =	($22,655.06	- $2,718.61)	x	0.05	= $996.82

NS = $996.82 - $100 = $896.82

$$SIR = \frac{\$996.82}{\$100} = 9.97$$

(D-2) With Replacement of Existing System with Gas Furnace

PV Cost = $100

	PV Space Heating	After R-19		% Reduction	
PV Savings =	($9,711.48	- $1,165.38)	x	0.05	= $427.31

NS = $427.31 - $100 = $327.31

$$SIR = \frac{\$427.31}{\$100} = \$4.27$$

(E) Addition of Attic Insulation, R-30 to R-38

Alternative (E) is conditional on Alternatives (C) and (D) being undertaken. It can be evaluated in terms of the incremental costs and savings over and above those associated with raising the R value to R-30.

(E-1) With Existing Electric Space Heating System

PV Cost = $75

		PV Space Heating After R-30				% Reduction	
PV Savings = ($22,655.06	-	$2,718.61	-	$996.82)	x	0.02	= $378.79

NS = $378.79 - $75 = $303.79

$$SIR = \frac{\$378.79}{\$75} = 5.05$$

(E-2) With Replacement of Existing System with Gas Furnace

PV Cost = $75

		PV Space Heating After R-30				% Reduction	
PV Savings = ($9,711.48	-	$1,165.38	-	$427.31)	x	0.02	= $162.38

NS = $162.38 - $75 = $87.38

$$SIR = \frac{\$162.38}{\$75} = 2.17$$

(F) Replacement of From One to Five Existing North-Facing Single-Glazed Windows with Double-Glazed Windows

(F-1) With Existing Electric Space Heating System

TABLE 7.14.1 EVALUATION OF WINDOW REPLACEMENT, ELECTRIC HEATING

No. Windows	PV Cost	PV Savings	NS	SIR
1	$ 200	$22,655.06 x 0.02 = $ 453.10	$ 253.10	2.27
2	400	22,655.06 x 0.04 = 906.20	506.20	2.27
3	600	22,655.06 x 0.06 = 1,359.30	759.30	2.27
4	800	22,655.06 x 0.08 = 1,812.40	1,012.40	2.27
5	1,000	22,655.06 x 0.10 = 2,265.51	1,265.51	2.27

(F-2) With Replacement of Existing System With Gas Furnace

TABLE 7.14.2 EVALUATION OF WINDOW REPLACEMENT, GAS HEATING

No. Windows	PV Cost	PV Savings	NS	SIR
1	$ 200	$9,711.48 x .02 = $194.23	$ - 5.77	0.97
2	400	9,711.48 x .04 = 388.46	-11.54	0.97
3	600	9,711.48 x .06 = 582.69	-17.31	0.97
4	800	9,711.48 x .08 = 776.92	-23.08	0.97
5	1,000	9,711.48 x .10 = 971.15	-28.85	0.97

(G) Addition of From One to Five North-Facing Storm Windows (Instead of Replacing Windows) and From One to Three East-Facing Storm Windows

(G-1) With Existing Electric Space Heating System

TABLE 7.14.3 EVALUATION OF STORM WINDOWS, ELECTRIC HEATING

No. Windows	PV Cost	PV Savings	NS	SIR
		North-Facing Windows		
1	$ 50	$22,655.06 x 0.018 = $ 407.79	$ 357.79	8.16
2	100	22,655.06 x 0.036 = $ 815.58	715.58	8.16
3	150	22,655.06 x 0.054 = 1,223.37	1,073.37	8.16
4	200	22,655.06 x 0.072 = 1,631.16	1,431.16	8.16
5	250	22,655.06 x 0.090 = 2,038.96	1,788.96	8.16
		East-Facing Windows		
1	$ 50	$22,655.06 x 0.007 = $158.59	$108.59	3.17
2	100	22,655.06 x 0.014 = 317.17	217.17	3.17
3	150	22,655.06 x 0.021 = 475.76	325.76	3.17

(G-2) With Replacement of Existing System With Gas Furnace

TABLE 7.14.4 EVALUATION OF STORM WINDOWS, GAS HEATING

No. Windows	PV Cost	PV Savings	NS	SIR
		North-Facing Windows		
1	$ 50	$9,711.48 x 0.018 = $174.81	$124.81	3.50
2	100	9,711.48 x 0.036 = 349.61	249.61	3.50
3	150	9,711.48 x 0.054 = 524.42	374.42	3.50
4	200	9,711.48 x 0.072 = 699.23	499.23	3.50
5	250	9,711.48 x 0.090 = 874.03	624.03	3.50
		East-Facing Windows		
1	$ 50	$9,711.48 x 0.007 = $ 67.98	$17.98	1.36
2	100	9.711.48 x 0.014 = 135.96	35.96	1.36
3	150	9,711.48 x 0.021 = 203.94	53.94	1.36

Now select projects from among the candidates in descending order of their SIR's until the $1,500 budget is exhausted. Table 7.14.5 lists that set of projects.

TABLE 7.14.5 PROJECT SELECTION

Priority Ranking	Investment Alternative	SIR	PV Cost	PV Savings	Net Savings
1	(B) Replace Space Heating System	12.94	$1,000	$12,944	$11,944
2	(C-2) Add R-11 to R-19 Attic Insulation	5.18	225	1,165	940
3	(D-2) Add R-19 to R-30 Attic Insulation	4.27	100	427	327
4	(G-2) Add 3 Storm Windows on North	3.50	150	524	374
Totals	4 projects	n.a.*	$1,475	$15,060	$13,585

* not applicable

The project given the highest priority on the basis of its SIR is (B), replacement of the electric resistance heating system with a gas furnace. Acceptance of that project means that, thereafter, projects which improve the thermal integrity of the shell of the house, such as the attic insulation and storm windows, must be evaluated on the basis of reductions in gas heating costs.

Given the "lumpiness" in project costs, the full $1,500 is not allocated, and $25 remains unallocated. Yet the net savings from undertaking these projects is greater than from any other combination of projects which <u>would</u> exhaust the total budget.

In conclusion, the package of energy conservation projects that will maximize net savings from the limited conservation budget of $1,500 consists of replacing the electric resistance space heating system with a gas furnace, increasing the attic insulation from R-11 to R-30, and outfitting 3 windows on the north side of the house with storm windows.

If the budget were not limited, it would pay to undertake all of the candidate projects except replacement of the north-facing windows with double-glazed windows.

7.15 Evaluating the After-Tax Economic Feasibility of a Commercial Investment in Energy Conservation[1]

Problem

The corporate owner of an existing industrial plant is seeking a lower cost method of providing space heating for the plant office space. Space heating is currently provided by an oil-fired furnace using No. 2 fuel oil. This system could continue to be used without major modification. Alternatively, a waste heat recovery system could be purchased and installed on the jacket of the plant exhaust stack to supplement the existing furnace and reduce its consumption of fuel oil by an estimated 90 percent. Based on the following data and assumptions given in table 7.15.1, and taking into account tax effects, determine if the investment in the waste heat recovery system will lower total life-cycle costs.

Solution

The two alternatives presented, (1) to continue using the existing furnace, or (2) to invest in the waste heat recovery system, can be compared on the basis of their total life-cycle costs, TLCC.

The TLCC of each alternative over the seven-year holding period is calculated and displayed in the series of tables that follow. Tables 7.15.2 through 7.15.4 give the year-by-year results for alternative 1, continuing to use the existing oil-fired furnace without modification. Tables 7.15.5 through 7.15.10 give the results for alternative 2, supplementing the existing system with a waste heat recovery system.

By comparing column 3 in table 7.15.4 and column 6 in table 7.15.10, we see that the TLCC of the waste heat recovery system is $5,825 less than the TLCC of the existing furnace, making the waste heat recovery system the preferred investment alternative on economic grounds.

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[1] This problem is based on an example contained in Appendix C of a recent National Bureau of Standards report: Rosalie T. Ruegg, Stephen R. Petersen, and Harold E. Marshall, Recommended Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, NBSIR (In Press, 1980).

TABLE 7.15.1 DATA AND ASSUMPTIONS

Time Horizon (Investor's Holding Period)[a]	7 years
Discount Rate	15%
Inflation Rate	8%
Investment Cost Data	
Purchase and Installation Price	$35,000
Down Payment	$ 3,500
Loan Interest Rate	12.5%
Loan Life	7 years
Yearly Loan Payment	$ 7,012
Asset Life	20 years
Depreciation (Straight-Line)	$ 1,750/year[b]
Loan Interest Payments, Tax Effects	Deductible from Taxable Income
Resale Value at End of 7 Years[c]	$\$22,750\ (1 + .08)^7$
Annually Recurring O&M (Non-Fuel) Costs	
Existing Furnace[d]	$ 500
Waste Heat Recovery System	$ 200
O&M Costs, Tax Effects	Deductible from Taxable Income
Energy Costs	
Fuel Consumption for Space Heating without Waste Heat Recovery	$1,000 \times 10^6$ Btu/year (1,055 GJ/year)
Fuel Consumption for Space Heating with Waste Heat Recovery	100×10^6 Btu/year (106 GJ/year)
Base Year Fuel Price	$\$5.69/10^6$ Btu ($5.39/GJ)
Fuel Price Escalation Rate, Compounded Annually	12%
Federal Corporate Tax Rates	46% income tax rate 28% capital gains rate
State Tax Rates	Not considered

[a] A relatively short time horizon was selected for this example to facilitate a year-by-year display of costs.

[b] Based on straight-line depreciation method, 20-year life, and a book value of $35,000.

[c] In this example, resale value is based on the remaining book value after seven years, adjusted for inflation over the seven-year holding period.

[d] Non-fuel O&M costs for the existing furnace are assumed to be unchanged by addition of the waste heat recovery system.

TABLE 7.15.2 ALTERNATIVE 1: FUEL COSTS WITHOUT ADDITION OF THE WASTE HEAT RECOVERY SYSTEM

(1) Year	(2) Today's Fuel Price, $\$/10^6$ Btu	(3) Annual Fuel Requirement, x 10^6 Btu	(4) Annual Fuel Cost at Today's Price, $ (2)x(3)	(5) Fuel Price Escalation Multiplier	(6) Annual Fuel Cost After Escalation, $ (4)x(5)	(7) Corporate Income Tax Rate, %	(8) Tax Reduction Due to Fuel Cost Deductions, $ (6)x(7)	(9) Annual Fuel Cost After Price Escalation and Tax, $ (6)-(8)	(10) SPW Factor i=15%	(11) PV of Annual Fuel Cost After Tax and Price Escalation, $ (9)x(10)
1	5.69	1,000	5,690	$(1 + .12)^1$	$ 6,372.80	46	2,931.49	3,441.31	0.8696	2,992.56
2	5.69	1,000	5,690	$(1 + .12)^2$	7,137.54	46	3,283.27	3,854.27	0.7561	2,914.21
3	5.69	1,000	5,690	$(1 + .12)^3$	7,994.04	46	3,677.26	4,316.78	0.6575	2,838.28
4	5.69	1,000	5,690	$(1 + .12)^4$	8,953.33	46	4,118.53	4,834.80	0.5718	2,764.54
5	5.69	1,000	5,690	$(1 + .12)^5$	10,027.72	46	4,612.75	5,414.97	0.4972	2,692.32
6	5.69	1,000	5,690	$(1 + .12)^6$	11,231.05	46	5,166.28	6,064.77	0.4323	2,621.80
7	5.69	1,000	5,690	$(1 + .12)^7$	12,578.78	46	5,786.24	6,792.54	0.3759	2,553.32
								TOTAL PV FUEL COSTS		$19,377.03

TABLE 7.15.3 ALTERNATIVE 1: O&M COSTS WITHOUT ADDITION OF THE WASTE HEAT RECOVERY SYSTEM

(1) Year	(2) Annual O&M Cost at Today's Prices, $	(3) Inflation Multiplier	(4) Annual O&M Cost After Inflation, $ (2)x(3)	(5) Corporate Income Tax Rate, %	(6) Tax Reduction Due to O&M Cost Deductions, $ (4)x(5)	(7) Annual O&M Cost After Tax and Inflation, $ (4)-(6)	(8) SPW Factor i=15%	(9) PV of Annual O&M Cost After Tax and Inflation, $ (7)x(8)
1	500	$(1 + .08)^1$	540.00	46	248.40	291.60	0.8696	253.58
2	500	$(1 + .08)^2$	583.20	46	268.27	314.93	0.7561	238.12
3	500	$(1 + .08)^3$	629.86	46	289.74	340.12	0.6575	223.63
4	500	$(1 + .08)^4$	680.24	46	312.91	367.33	0.5718	210.04
5	500	$(1 + .08)^5$	734.66	46	337.94	396.72	0.4972	197.25
6	500	$(1 + .08)^6$	793.44	46	364.98	428.46	0.4323	185.22
7	500	$(1 + .08)^7$	856.91	46	394.18	462.73	0.3759	173.94

TOTAL PV O&M COSTS $1,481.78

TABLE 7.15.4 ALTERNATIVE 1: TLCC OF CONTINUING USE OF THE EXISTING FURNACE WITHOUT ADDITION OF THE WASTE HEAT RECOVERY SYSTEM

(1) PV of Fuel Costs, $	(2) PV of O&M, $	(3) TLCC, $ (1) + (2)
19,377.03	1,481.78	20,859

TABLE 7.15.5 ALTERNATIVE 2: FUEL COSTS WITH THE WASTE HEAT RECOVERY SYSTEM

(1) Year	(2) Today's Fuel Price, $\$/10^6$ Btu	(3) Annual Fuel Requirement, $x\ 10^6$ Btu	(4) Annual Fuel Cost at Today's Price, $ (2)x(3)	(5) Fuel Price Escalation Multiplier	(6) Annual Fuel Cost After Escalation, $ (4)x(5)	(7) Corporate Income Tax Rate, %	(8) Tax Reduction Due to Fuel Cost Deductions, $ (6)x(7)	(9) Annual Fuel Cost After Price Escalation and Tax, $ (6)-(8)	(10) SPW Factor i=15%	(11) PV of Annual Fuel Cost After Tax and Price Escalation, $ (9)x(10)
1	5.69	100	569	$(1 + .12)^1$	637.28	46	293.15	344.13	0.8696	299.26
2	5.69	100	569	$(1 + .12)^2$	713.75	46	328.33	385.42	0.7561	291.42
3	5.69	100	569	$(1 + .12)^3$	799.40	46	367.72	431.68	0.6575	283.83
4	5.69	100	569	$(1 + .12)^4$	895.33	46	411.85	483.48	0.5718	276.45
5	5.69	100	569	$(1 + .12)^5$	1,002.77	46	461.27	541.50	0.4972	269.23
6	5.69	100	569	$(1 + .12)^6$	1,123.11	46	516.63	606.48	0.4323	262.18
7	5.69	100	569	$(1 + .12)^7$	1,257.88	46	578.62	679.26	0.3759	255.33

TOTAL PV FUEL COSTS $1,937.70

TABLE 7.15.6 ALTERNATIVE 2: PURCHASE AND INSTALLATION COST OF THE WASTE HEAT RECOVERY SYSTEM

(1) Year	(2) Down Payment, $	(3) Annual Loan Payment, $	(4) UPW Factor i=15% n=7	(5) PV of Loan Payments, $ $7,012 x 4.160	(6) Interest Payments[a], $	(7) Corporate Income Tax Rate, %	(8) Tax Reductions From Interest Deductions, $ (6)x(7)	(9) SPW Factors i=15%	(10) PV of Tax Reductions, $ (8)x(9)	(11) PV of After-Tax, After-Inflation Investment Cost (2)+(5)-(10)[b]
0	3,500	--	--	29,169.92	--	--	--	--	--	--
1	--	7,012	4.160	--	3,937.50	46	1,811.25	0.8696	1,575.06	--
2	--	7,012	--	--	3,553.19	46	1,634.47	0.7561	1,235.82	--
3	--	7,012	--	--	3,120.84	46	1,435.59	0.6575	943.90	--
4	--	7,012	--	--	2,634.44	46	1,211.84	0.5718	692.93	--
5	--	7,012	--	--	2,087.25	46	960.14	0.4972	477.38	--
6	--	7,012	--	--	1,471.65	46	676.96	0.4323	292.65	--
7	--	7,012	--	--	779.11	46	358.39	0.3759	134.72	--
Total Present Value	$3,500	--	--	$29,169.96	--	--	--	--	$5,352.46	$27,317.46

[a] Interest payments are calculated in the following manner:

$$I_n = P_n \times i,$$

where $P_n = P_{n-1} - (F_{n-1} - I_{n-1})$,

and I = interest payment
n = year in which interest payment is sought
P = loan principal
i = loan interest rate
F = annual loan payment,

so that, for example, the interest payment for year 2 is:

$$[31,500 - (7,012 - 3,937.50)] \times .125 = 3553.19$$

[b] Calculated from the total present values of columns 2, 5, and 10.

TABLE 7.15.7 ALTERNATIVE 2: DEPRECIATION ALLOWANCES FOR THE WASTE HEAT RECOVERY SYSTEM

(1)	(2)	(3)	(4)	(5)
Annual Depreciation Allowance, $	Corporate Income Tax Rate, %	Annual Tax Reduction Due to Depreciation Allowance, $ (1) x (2)	UPW Factor i = 15% n = 7	PV of 7 years of Tax Reductions Due to Depreciation, After Inflation, $ (3) x (4)
1,750	46	805	4.160	3,348.80

TABLE 7.15.8 ALTERNATIVE 2: RESALE VALUE, NET OF CAPITAL GAINS TAX, FOR THE WASTE HEAT RECOVERY SYSTEM

(1) Year	(2) Resale Value, End of 7 Years, $	(3) Book Value, End of 7 years, $[a]	(4) Capital Gains, $ (2)-(3)	(5) Capital Gains Tax Rate, %	(6) Capital Gains Tax, $ (4)x(5)	(7) Resale Value Net of Capital Gains Tax, $ (2)-(6)	(8) SPW Factor, i=15% n=7	(9) PV of Resale Value, After Capital Gains Tax and Inflation $ (7)x(8)
7	38,989.50	22,750.00	16,239.50	28	4,547.06	34,442.44	0.3759	12,946.91

[a] Based on the original book value of $35,000 and 7 years of depreciation of $1,750 per year.

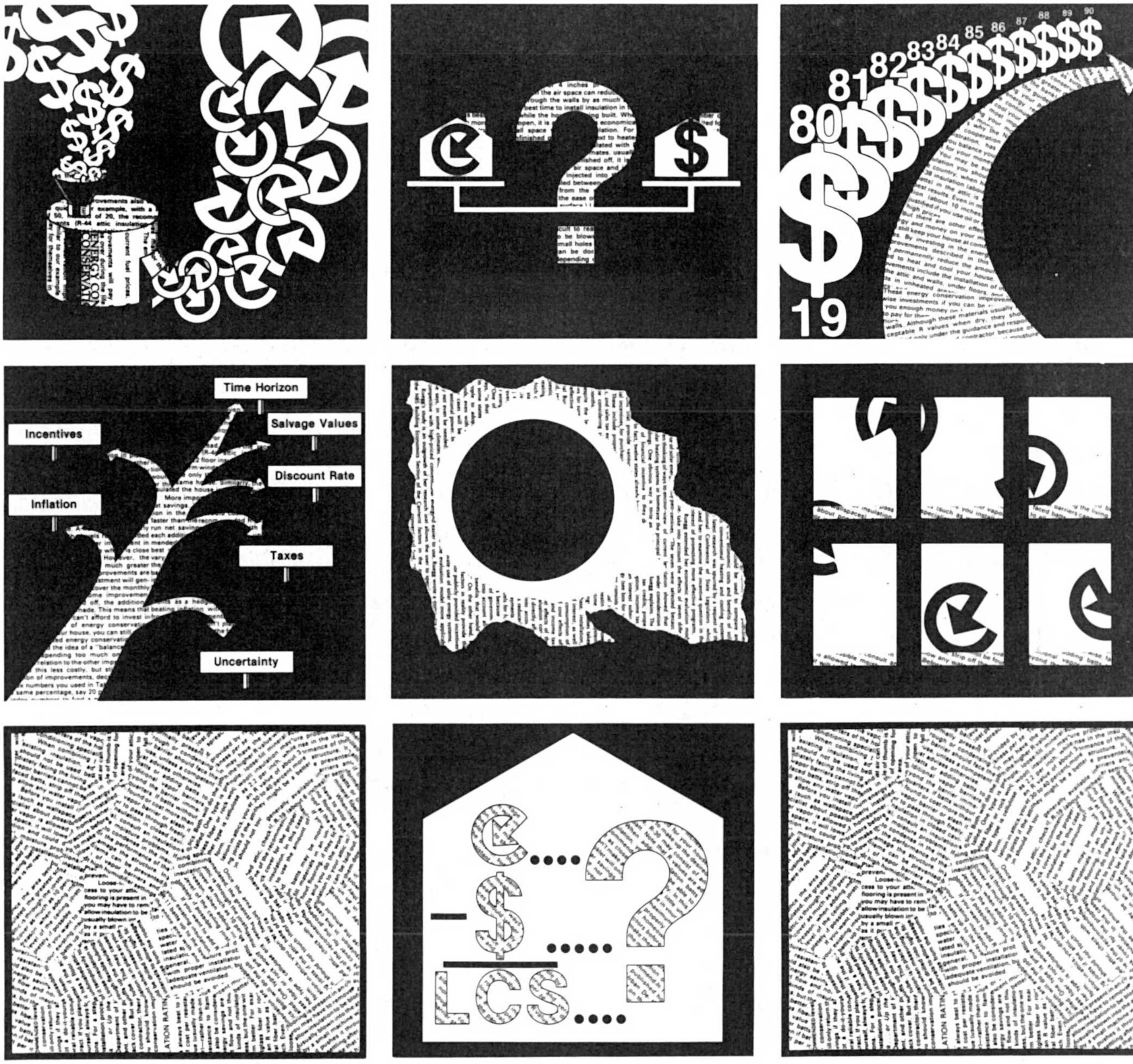
TABLE 7.15.9 ALTERNATIVE 2: NON-FUEL O&M COSTS WITH ADDITION OF THE WASTE HEAT RECOVERY SYSTEM

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Year	Annual O&M Cost[a] at Today's Prices, $	Inflation Multiplier	Annual O&M Cost After Inflation, $ (2)x(3)	Corporate Income Tax Rate, %	Tax Reduction Due to O&M Cost Deductions, $ (4)x(5)	Annual O&M Cost After Tax and Inflation, $ (4)-(6)	SPW Factor i=15%	PV of Annual O&M Cost After Tax and Inflation, $ (7)x(8)
1	700	$(1 + .08)^1$	756.00	46	347.76	408.24	0.8696	355.01
2	700	$(1 + .08)^2$	816.48	46	375.58	440.90	0.7561	333.36
3	700	$(1 + .08)^3$	881.80	46	405.63	476.17	0.6575	313.08
4	700	$(1 + .08)^4$	952.34	46	438.08	514.26	0.5718	294.05
5	700	$(1 + .08)^5$	1,028.53	46	473.12	555.41	0.4972	276.15
6	700	$(1 + .08)^6$	1,110.81	46	510.97	599.84	0.4323	259.31
7	700	$(1 + .08)^7$	1,199.68	46	551.85	647.83	0.3759	243.52
						TOTAL PV O&M COSTS		$2,074.48

[a] Includes the combined annual O&M cost at today's prices for the existing system ($500) and the waste heat recovery system ($200)

TABLE 7.15.10 ALTERNATIVE 2: TLCC WITH ADDITION OF THE WASTE HEAT RECOVERY SYSTEM

(1) PV of Fuel Costs After Taxes and Price Escalation, $	(2) PV of Investment Costs, After Taxes and Inflation, $	(3) PV of Tax Reductions Due to Depreciation Allowance, After Inflation, $	(4) PV of Resale Value, After Taxes and Inflation, $	(5) PV of O&M After Taxes and Inflation, $	(6) TLCC, After Taxes and Inflation, $ (1) + (2) - (3) - (4) + (5)
1,937.70	27,317.46	3,348.80	12,946.91	2,074.48	15,034



8. Summary

From 1970 to 1976 in the United States, the unit price of energy for buildings rose 39 percent, and the current dollar consumption increased by over 28 billion dollars. As a result, architects, builders, and others concerned with the design and operation of buildings have become increasingly concerned with planning and producing energy efficient buildings. The interest in conservation in buildings is based on the current and impending physical scarcities of fuels as well as the opportunity to save money through reduced fuel bills. All sectors of the building community need principles and guidelines for making economically efficient investment decisions in energy conservation. Textbooks and courses in traditional microeconomic theory and engineering economics have devoted little attention to specific economic guidelines for energy conservation investments in buildings.

The purpose of this handbook is to provide principles, techniques of problem solving, step-by-step case illustrations, and a self-instruction problem set that will serve as an aid to problem solving and a guide to decisions for practicing professionals and building owners who make decisions about energy conservation in new and existing buildings. This group includes architects, mechanical engineers, designers, builders, codes and standards writers, and government policy makers. The handbook has presented standardized economic approaches for a variety of energy conservation and solar energy investment decisions, with emphasis on practical methods of problem solving.

Section 2 explained the concept of economic efficiency, discussed the measurement of benefits and costs, and provided a general description of five commonly used techniques of economic analysis: total life-cycle costing technique, net benefits (savings) technique, savings-to-investment ratio technique, internal rate-of-return technique, and discounted payback technique. Advantages and disadvantages were discussed for each technique. Suggestions were made for selecting the appropriate technique for treating specific types of investment problems in energy conservation and solar energy.

Discounting, a procedure for taking into account the time value of money, was described in Section 3. A problem on the economics of heat pumps illustrated the various discounting procedures.

The factors that significantly affect benefits and costs were identified and discussed in section 4. Guidance was provided for selecting appropriate values of these factors for making economic evaluations. The implications of selecting inappropriate values were also discussed. Time horizons, discount rates, inflation, incentives, taxes, salvage values, and measures of uncertainty were included.

Sections 5 and 6 provided comprehensive case illustrations for solar heating and window design and management, respectively. For each case, energy conservation options were described and an appropriate technique of economic analysis was applied to select the economically efficient option.

Section 7 presented, in increasing order of difficulty, 15 problems with solutions ranging from very simple to complex. The solutions to the energy conservation and solar energy problems were worked out step-by-step to facilitate self-instruction in the development of skills in applying the principles and techniques presented in the handbook.

Concluding the report is a series of appendices that define economic terms and provide tables and formulas for discounting operations.

There are three anticipated impacts of applying the principles and guidelines presented in this handbook to the design of new buildings and to the retrofit of existing buildings: (1) a reduction in conservation costs to achieve given energy conservation goals; (2) an increase in energy conserved for a given conservation budget; and (3) more economically efficient buildings.

APPENDIX A

Glossary of Economic Terms

ANNUALLY RECURRING COSTS - Those costs which are incurred each year in an equal amount or in an amount that is increasing at a constant rate throughout the study period.

ANNUAL VALUE - Project costs or benefits expressed as an equivalent uniform annual amount, taking into account the time value of money.

BASE YEAR - The time to which all future and past costs are converted when a present value method is used, usually the beginning of the study period.

BENEFIT-COST ANALYSIS - A method of evaluating projects or investments by comparing the discounted present value or annual value of total expected benefits with the discounted present value or annual value of total expected costs.

BENEFIT-COST RATIO (B/C) - Benefits expressed as a proportion of costs, where both are discounted to a present or annual value; must be greater than one for an investment to be economically justified on the basis of dollar measureable benefits and costs.

CONSTANT DOLLARS - Values expressed in terms of the purchasing power of the dollar in a given year, usually the base year; i.e., constant dollars do not reflect price inflation.

COST EFFECTIVE - Estimated benefits (savings) from an investment project are equal to or exceed the costs of the investment, where both are assessed over the life of the project and discounted to reflect the time value of money.

CURRENT DOLLARS - Values expressed in terms of the actual prices of each year; i.e., current dollars reflect inflation.

DIFFERENTIAL COST - The difference in a component of cost or in the total cost of two alternatives.

DIFFERENTIAL PRICE ESCALATION RATE - The expected difference between a general rate of inflation and the rate of increase assumed for a given cost component.

DISCOUNT FACTOR - A multiplicative number, calculated from a discount formula for a given discount rate and interest period, used to convert costs and benefits occurring at different times to a common basis.

DISCOUNT RATE - The rate of interest reflecting the time value of money, used in discounting formulas and to compute discounting factors for converting benefits and costs occurring at different times to a common time.

DISCOUNTED PAYBACK PERIOD (DPB) - The time required for the cumulative benefits from an investment to pay back the investment cost and other accrued costs, considering the time value of money.

DISCOUNTING - A technique for converting cash flows that occur over time to equivalent amounts at a common point in time.

ECONOMIC LIFE - That period of time over which an investment is considered to be the least-cost alternative for meeting a particular objective.

FIRST COST - The sum of the planning, design, and construction costs necessary to provide a finished building or building component ready for use, sometimes called initial investment cost.

FUTURE VALUE (WORTH) - The value of a dollar amount at some point in the future, considering the time value of money.

INFLATION - A rise in the general price level, or, put another way, a decline in the general purchasing power of the dollar.

INITIAL INVESTMENT COST - The sum of the planning, design, and construction costs necessary to provide a finished building or building component ready for use, sometimes called the first cost.

INTERNAL RATE OF RETURN (IRR) - The compound rate of interest which, when used to discount the life-cycle costs and benefits of a project, will cause the two to be equal.

LIFE CYCLE - The period of time between the starting point and cutoff date for analysis, over which the costs and benefits of a certain alternative are incurred, sometimes called the study period or time horizon.

LIFE-CYCLE COSTING (LCC) - A general method of economic evaluation which considers all relevant costs associated with an activity or project during its time horizon, comprising the techniques of total life-cycle costs, net benefits, internal rate of return, and savings-to-investment (benefit-cost) ratio analysis.

MAINTENANCE AND REPAIR COST - The total of labor, material, transportation, and other related costs incurred in conducting corrective and preventative maintenance and repair on a building and/or its systems, components, and equipment.

MAJOR REPLACEMENT COST - Any significant future component replacement, included in the capital budget, which must be incurred during the study period in order to maintain the investment at a functional level.

NET BENEFITS (NB) - The difference between the benefits and the costs, evaluated in present or annual value dollars, attributable to a project, activity, or design alternative.

NET PRESENT VALUE OF INVESTMENT-RELATED COSTS - The present value of the initial investment costs plus the present value of replacement costs less the present value of salvage values.

NET SAVINGS (NS) - The difference between the savings and the costs, calculated in present or annual value dollars, attributable to a project, activity, or design alternative.

NOMINAL DISCOUNT RATE - The rate of interest reflecting the time value of money stemming both from inflation and the real earning power of money over time, used in discount formulas or to select discount factors for converting current dollar benefits and costs to a common time.

OPERATING COST - The expenses incurred during the normal operation of a building, building system, component, or equipment, including costs of labor, materials, and utilities.

OPPORTUNITY COST OF CAPITAL - The rate of return available on the next best available investment, indicative of the appropriate value of the discount rate.

PRESENT VALUE (WORTH) - The value of a benefit or cost at the present time (i.e., in the base year), found by discounting cash flows occurring in the future to the present.

PRESENT VALUE FACTOR - The discounting factor by which a future value may be multiplied to find its value at the present time (i.e., in the base year) given a discount rate.

REAL DISCOUNT RATE - The rate of interest reflecting that part of the time value of money related to the real earning power of money over time, used in discount formulas or to select discount factors for converting constant dollar benefits and costs to a common time.

SALVAGE VALUE - The net sum to be realized from disposal or sale of an asset at the end of its economic life, at the end of the study period, or when it is no longer to be used.

SAVINGS-TO-INVESTMENT RATIO (SIR) - Either the ratio of present value savings to present value investment costs, or the ratio of annual value savings to annual value investment costs.

SENSITIVITY ANALYSIS - Testing the outcome of an evaluation by altering one or more parameters from the initially assumed value(s).

SIMPLE PAYBACK PERIOD (SPB) - A measure of the length of time required for the cumulative benefits, net of cumulative future costs, from an investment to pay back the initial investment cost, without taking into account the time value of money.

STUDY PERIOD - The length of time over which an investment is analyzed, sometimes referred to as the time horizon or life cycle.

SUNK COST - A cost which has already been incurred and should not be considered in making a current investment decision.

TIME HORIZON - The length of time over which an investment is analyzed, sometimes referred to as the study period or life-cycle.

TIME VALUE OF MONEY - The time-dependent value of money that may stem both from changes in the purchasing power of money (i.e., inflation or deflation), and from the real earning potential of alternative investments over time. The time value of money is indicated by the rate of interest which will cause the value of a dollar received at some future time to be equivalent in value to a dollar received today.

TOTAL LIFE-CYCLE COSTING (TLCC) - A technique of life-cycle costing which finds the sum of the costs of an initial investment (less salvage value), replacements, operations including energy use, and maintenance and repair, over the life-cycle of an investment, expressed in present or annual value terms.

USEFUL LIFE - The period over which an investment continues to generate benefits or savings.

APPENDIX B
DISCOUNT FORMULAS

Formula Name	Illustration	Use	Algebraic Form
Single Compound Amount Formula (SCA)	[P] → [F?]	To find F when P is known	$F = P(1 + i)^N$
Single Present Value Formula (SPW)	[P?] ← [F]	To find P when F is known	$P = F \frac{1}{(1 + i)^N}$
Uniform Sinking Fund Formula (USF)	[A?] + [A?] + [A?] .. [A?] → [F]	To find A when F is known	$A = F \frac{1}{(1 + i)^N - 1}$
Uniform Capital Recovery Formula (UCR)	[P] → [A?] + [A?] + [A?] .... [A?]	To find A when P is known	$A = P \frac{i(1 + i)^N}{(1 + i)^N - 1}$
Uniform Compound Amount Formula (UCA)	[A] + [A] + [A] .. [A] → [F?]	To find F when A is known	$F = A \frac{(1 + i)^N - 1}{i}$
Uniform Present Value Formula (UPW)	[P?] ← [A] + [A] + [A] ... [A]	To find P when A is known	$P = A \frac{(1 + i)^N - 1}{i(1 + i)^N}$
Uniform Present Value Formula Modified (UPW*)	[P?] ← [A] + [A] + [A] ... [A]	To find P when A is escalating at rate e[§]	$P = A\left(\frac{1 + e}{i - e}\right)\left[1 - \left(\frac{1 + e}{1 + i}\right)^N\right]$

Where:

P = a present sum of money.

F = a future sum of money.

i = an interest or discount rate.

N = number of interest or discounting periods.

A = an end-of-period payment (or receipt) in a uniform series of payments (or receipts) over N periods at i interest or discount rate.

e = rate of escalation of A in each of N periods.

F? = indicates a future value to be found; P?, a present value to be found; and A?, an annual value to be found.

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§ To find P when A is escalating at a different rate over each of the k escalation periods,

$$P = A \sum_{j=1}^{k} UPV^{*}_{i,e_j,N_j} \Pi_j \left(\frac{1 + e_{j-1}}{1 + i}\right)^{N_{j-1}}, \text{ where } e_o \text{ and } N_o = 0$$

APPENDIX C

DISCOUNT FACTORS

TABLE C-1 6% DISCOUNT FACTORS

n 1	Compound amount factor SCA 2	Present worth factor SPW 3	Sinking fund factor USF 4	Capital recovery factor UCR 5	Compound amount factor UCA 6	Present worth factor UPW 7	n
1	1.0600	0.9434	1.00000	1.06000	1.000	0.943	1
2	1.1236	0.8900	0.48544	0.54544	2.060	1.833	2
3	1.1910	0.8396	0.31411	0.37411	3.184	2.673	3
4	1.2625	0.7921	0.22859	0.22859	4.375	3.465	4
5	1.3382	0.7473	0.17740	0.27340	5.637	4.212	5
6	1.4185	0.7050	0.14336	0.20336	6.975	4.917	6
7	1.5036	0.6641	0.11914	0.17914	8.394	5.582	7
8	1.5938	0.6274	0.10104	0.16104	9.897	6.210	8
9	1.6895	0.5919	0.08702	0.14702	11.491	6.802	9
10	1.7908	0.5584	0.70587	0.13587	13.181	7.360	10
11	1.8983	0.5268	0.06679	0.12679	14.972	7.887	11
12	2.0122	0.4970	0.05928	0.11928	16.870	8.384	12
13	2.1329	0.4688	0.05296	0.11296	18.882	8.853	13
14	2.2609	0.4423	0.04758	0.10758	21.015	9.295	14
15	2.3966	0.4173	0.04296	0.10296	23.276	9.712	15
16	2.5404	0.3936	0.03895	0.09895	25.673	10.106	16
17	2.6928	0.3714	0.03544	0.09544	28.213	10.477	17
18	2.8543	0.3503	0.03236	0.09236	30.906	10.828	18
19	3.0256	0.3305	0.02962	0.08962	33.760	11.158	19
20	3.2071	0.3118	0.02718	0.08718	36.786	11.470	20
21	3.3996	0.2942	0.02500	0.08500	39.993	11.764	21
22	3.6035	0.2775	0.02305	0.08305	43.392	12.042	22
23	3.8197	0.2618	0.02128	0.08128	46.996	12.303	23
24	4.0489	0.2470	0.01968	0.07968	50.816	12.550	24
25	4.2919	0.2330	0.01823	0.07823	54.865	12.783	25
26	4.5494	0.2198	0.01690	0.07690	59.156	13.003	26
27	4.8223	0.2074	0.01570	0.07570	63.706	13.211	27
28	5.1117	0.1956	0.01459	0.07459	68.528	13.406	28
29	5.4184	0.1846	0.01358	0.07358	73.640	13.591	29
30	5.7435	0.1741	0.01265	0.07265	79.058	13.765	30
31	6.0881	0.1643	0.01179	0.07179	84.802	13.929	31
32	6.4534	0.1550	0.01100	0.07100	90.890	14.084	32
33	6.8406	0.1462	0.01027	0.07027	97.343	14.230	33
34	7.2510	0.1379	0.00960	0.06960	104.184	14.368	34
35	7.6861	0.1301	0.00897	0.06897	111.435	14.498	35
40	10.2857	0.0972	0.00646	0.06646	154.762	15.046	40
45	13.7646	0.0727	0.00470	0.06470	212.744	15.456	45
50	18.4202	0.0543	0.00344	0.06344	290.336	15.762	50
55	24.6503	0.0406	0.00254	0.06254	394.172	15.991	55
60	32.9877	0.0303	0.00188	0.06188	533.128	16.161	60
65	44.1450	0.0227	0.00139	0.06139	719.083	16.289	65
70	59.0759	0.0169	0.00103	0.06103	967.932	16.385	70
75	79.0569	0.0126	0.00077	0.06077	1300.949	16.456	75
80	105.7960	0.0095	0.00057	0.06057	1746.600	16.509	80
85	141.5789	0.0071	0.00043	0.06043	2342.982	16.549	85
90	189.4645	0.0053	0.00032	0.06032	3141.075	16.579	90
95	253.5463	0.0039	0.00024	0.06024	4209.104	16.601	95
100	339.3021	0.0029	0.00018	0.06018	5638.368	16.618	100

TABLE C-2 8% DISCOUNT FACTORS

n	Compound amount factor SCA	Present worth factor SPW	Sinking fund factor USF	Capital recovery factor UCR	Compound amount factor UCA	Present worth factor UPW	
1	2	3	4	5	6	7	
1	1.0800	0.9259	1.00000	1.08000	1.000	0.926	1
2	1.6640	.8573	0.48077	0.56077	2.080	1.783	2
3	1.2597	.7938	.30803	.38803	3.246	2.577	3
4	1.3605	.7350	.22192	.30192	4.506	3.312	4
5	1.4693	.6806	.17046	.25046	5.867	3.993	5
6	1.5869	.6302	.13632	.21632	7.336	4.623	6
7	1.7138	.5835	.11207	.19207	8.923	5.206	7
8	1.8509	.5403	.09401	.17401	10.637	5.747	8
9	1.9990	.5002	.08008	.16008	12.488	6.247	9
10	2.1589	.4632	.06903	.14903	14.487	6.710	10
11	2.3316	.4289	.06008	.14008	16.645	7.139	11
12	2.5182	.3971	.05270	.13270	18.977	7.536	12
13	2.7196	.3677	.04652	.12652	21.495	7.904	13
14	2.9372	.3405	.04130	.12130	24.215	8.244	14
15	3.1722	.3152	.03683	.11683	27.152	8.559	15
16	3.4259	.2919	.03298	.11298	30.324	8.851	16
17	3.7000	.2703	.02963	.10963	33.750	9.122	17
18	3.9960	.2502	.02670	.10670	37.450	9.372	18
19	4.3157	.2317	.02413	.10413	41.446	9.604	19
20	4.6610	.2145	.02185	.10185	45.762	9.818	20
21	5.0338	.1987	.01983	.09983	50.423	10.017	21
22	5.4365	.1839	.01803	.09803	55.457	10.201	22
23	5.8715	.1703	.01642	.09642	60.893	10.371	23
24	6.3412	.1577	.01498	.09498	66.765	10.529	24
25	6.8485	.1460	.01368	.09368	73.106	10.675	25
26	7.3964	.1352	.01251	.09251	79.954	10.810	26
27	7.9881	.1252	.01145	.09145	87.351	10.935	27
28	8.6271	.1159	.01049	.09049	95.339	11.051	28
29	9.3173	.1073	.00962	.08962	103.966	11.158	29
30	10.0627	.0994	.00883	.08883	113.283	11.258	30
31	10.8677	.0920	.00811	.08811	123.346	11.350	31
32	11.7371	.0852	.00745	.08745	134.214	11.435	32
33	12.6760	.0789	.00685	.08685	145.951	11.514	33
34	13.6901	.0730	.00630	.08630	158.627	11.587	34
35	14.7853	.0676	.00580	.08580	172.317	11.655	35
40	21.7245	.0460	.00386	.08386	259.057	11.925	40
45	31.9204	.0313	.00259	.08259	386.506	12.108	45
50	46.9016	.0213	.00174	.08174	573.770	12.233	50
55	68.9139	.0145	.00118	.08118	848.923	12.319	55
60	101.2571	.0099	.00080	.08080	1253.213	12.377	60
65	148.7798	.0067	.00054	.08054	1847.248	12.416	65
70	218.6064	.0046	.00037	.08037	2720.080	12.443	70
75	321.2045	.0031	.00025	.08025	4002.557	12.461	75
80	471.9548	.0021	.00017	.08017	5886.935	12.474	80
85	693.4565	.0014	.00012	.08012	8655.706	12.482	85
90	1018.9151	.0010	.00008	.08008	12723.939	12.488	90
95	1497.1205	.0007	.00005	.08005	18701.507	12.492	95
100	2199.7613	.0005	.00004	.08004	27484.516	12.494	100

TABLE C-3 10% DISCOUNT FACTORS

n 1	Compound amount factor SCA 2	Present worth factor SPW 3	Sinking fund factor USF 4	Capital recovery factor UCR 5	Compound amount factor UCA 6	Present worth factor UPW 7	n
1	1.1000	0.9091	1.00000	1.10000	1.000	0.909	1
2	1.2100	0.8264	0.47619	0.57619	2.100	1.736	2
3	1.3310	0.7513	0.30211	0.40211	3.310	2.487	3
4	1.4641	0.6830	0.21547	0.31547	4.641	3.170	4
5	1.6105	0.6209	0.16380	0.26380	6.105	3.791	5
6	1.7716	0.5645	0.12961	0.22961	7.716	4.355	6
7	1.9487	0.5132	0.10541	0.20541	9.487	4.868	7
8	2.1436	0.4665	0.08744	0.18744	11.436	5.335	8
9	2.3579	0.4241	0.07364	0.17364	13.579	5.759	9
10	2.5937	0.3855	0.06275	0.16275	15.937	6.144	10
11	2.8531	0.3505	0.05396	0.15396	18.531	6.495	11
12	3.1384	0.3186	0.04676	0.14676	21.384	6.814	12
13	3.4523	0.2897	0.04078	0.14078	24.523	7.103	13
14	3.7975	0.2633	0.03575	0.13575	27.975	7.367	14
15	4.1772	0.2394	0.03147	0.13147	31.772	7.606	15
16	4.5950	0.2176	0.02782	0.12782	35.950	7.824	16
17	5.0545	0.1978	0.02466	0.12466	40.545	8.022	17
18	5.5599	0.1799	0.02193	0.12193	45.599	8.201	18
19	6.1159	0.1635	0.01955	0.11955	51.159	8.365	19
20	6.7275	0.1486	0.01746	0.11746	57.275	8.514	20
21	7.4002	0.1351	0.01562	0.11562	64.002	8.649	21
22	8.1403	0.1228	0.01401	0.11401	71.403	8.772	22
23	8.9543	0.1117	0.01257	0.11257	79.543	8.883	23
24	9.8497	0.1015	0.01130	0.11130	88.497	8.985	24
25	10.8347	0.0923	0.1017	0.11017	98.347	9.077	25
26	11.9182	0.0839	0.00916	0.10916	109.182	9.161	26
27	13.1100	0.0763	0.00826	0.10826	121.100	9.237	27
28	14.4210	0.0693	0.00745	0.10745	134.210	9.307	28
29	15.8631	0.0630	0.00673	0.10673	148.631	9.370	29
30	17.4494	0.0573	0.00609	0.10608	164.494	9.427	30
31	19.1943	0.0521	0.00550	0.10550	181.943	9.479	31
32	21.1138	0.0474	0.00497	0.10497	201.138	9.526	32
33	23.2252	0.0431	0.00450	0.10450	222.252	9.569	33
34	25.5477	0.0391	0.00407	0.10407	245.477	9.609	34
35	28.1024	0.0356	0.03369	0.10369	271.024	9.644	35
40	45.2593	0.0221	0.00226	0.10226	442.593	9.779	40
45	72.8905	0.0137	0.00139	0.10139	718.905	9.863	45
50	117.3909	0.0085	0.00086	0.10086	1163.909	9.915	50
55	189.0591	0.0053	0.00053	0.10053	1880.591	9.947	55
60	304.4816	0.0033	0.00033	0.10033	3034.816	9.967	60
65	490.3707	0.0020	0.00020	0.10020	4893.707	9.980	65
70	789.7470	0.0013	0.00013	0.10013	7887.470	9.987	70
75	1271.8952	0.0008	0.00008	0.10008	12708.954	9.992	75
80	2048.4002	0.0005	0.00005	0.10005	20474.002	9.995	80
85	3298.9690	0.0003	0.00003	0.10003	32979.690	9.997	85
90	5313.0226	0.0002	0.00002	0.10002	53120.226	9.998	90
95	8556.6760	0.0001	0.00001	0.10001	85556.760	9.999	95
100	13780.6123	0.0001	0.00001	0.10001	137796.123	9.999	100

TABLE C-4 12% DISCOUNT FACTORS

n 1	Compound amount factor SCA 2	Present worth factor SPW 3	Sinking fund factor USF 4	Capital recovery factor UCR 5	Compound amount factor UCA 6	Present worth factor UPW 7	n
1	1.1200	0.8929	1.00000	1.12000	1.000	0.893	1
2	1.2544	0.7972	0.47170	0.59170	2.120	1.690	2
3	1.4049	0.7118	0.29635	0.41635	3.374	2.402	3
4	1.5735	0.6355	0.20923	0.32923	4.779	3.037	4
5	1.7623	0.5674	0.15741	0.27741	6.353	3.605	5
6	1.9738	0.5066	0.12323	0.24323	8.115	4.111	6
7	2.2107	0.4523	0.09912	0.21912	10.089	4.564	7
8	2.4760	0.4039	0.08130	0.20130	12.300	4.968	8
9	2.7731	0.3606	0.06768	0.18768	14.776	5.328	9
10	3.1058	0.3220	0.05698	0.17698	17.549	5.650	10
11	3.4785	0.2875	0.04842	0.16842	20.655	5.938	11
12	3.8960	0.2567	0.04144	0.16144	24.133	6.194	12
13	4.3635	0.2292	0.03568	0.15568	23.029	6.424	13
14	4.8871	0.2046	0.03087	0.15087	32.393	6.628	14
15	5.4736	0.1827	0.02682	0.14682	37.280	6.811	15
16	6.1304	0.1631	0.02339	0.14339	42.753	6.974	16
17	6.8660	0.1456	0.02046	0.14046	48.884	7.120	17
18	7.6900	0.1300	0.01794	0.13794	55.750	7.250	18
19	8.6463	0.1161	0.01576	0.13576	63.440	7.366	19
20	9.6463	0.1037	0.01388	0.13388	72.052	7.469	20
21	10.8038	0.0926	0.01224	0.13224	81.699	7.562	21
22	12.1003	0.0826	0.01081	0.13081	92.503	7.645	22
23	13.5523	0.0738	0.00956	0.12956	104.603	7.718	23
24	15.1786	0.0659	0.00846	0.12846	118.155	7.784	24
25	17.0001	0.0588	0.00750	0.12750	133.334	7.843	25
26	19.0401	0.0525	0.00665	0.12665	150.334	7.896	26
27	21.3249	0.0469	0.00590	0.12590	169.374	7.943	27
28	23.8839	0.0419	0.00524	0.12524	190.699	7.984	28
29	26.7499	0.0374	0.00466	0.12466	214.583	8.022	29
30	29.9599	0.0334	0.00414	0.12414	241.333	8.055	30
31	33.5551	0.0298	0.00369	0.12369	271.292	8.085	31
32	37.5817	0.0266	0.00328	0.12328	304.847	8.112	32
33	42.0915	0.0238	0.00292	0.12292	342.429	8.135	33
34	47.1425	0.0212	0.00260	0.12260	384.520	8.157	34
35	52.7996	0.0189	0.00232	0.12232	431.663	8.176	35
40	93.0510	0.0107	0.00130	0.12130	767.091	8.244	40
45	163.9876	0.0061	0.00074	0.12074	1358.230	8.283	45
50	289.0022	0.0035	0.00042	0.12042	2400.018	8.305	50

TABLE C-5 15% DISCOUNT FACTORS

n 1	Compound amount factor SCA 2	Present worth factor SPW 3	Sinking fund factor USF 4	Capital recovery factor UCR 5	Compound amount factor UCA 6	Present worth factor UPW 7	n
1	1.1500	0.8696	1.00000	1.15000	1.000	0.870	1
2	1.3225	0.7561	0.46512	0.61512	2.150	1.626	2
3	1.5209	0.6575	0.28798	0.43798	3.472	2.283	3
4	1.7490	0.5718	0.20026	0.35027	4.993	2.855	4
5	2.0114	0.4972	0.14832	0.29832	6.742	3.352	5
6	2.3131	0.4323	0.11424	0.26424	8.754	3.784	6
7	2.6600	0.3759	0.09036	0.24036	11.067	4.160	7
8	3.0590	0.3269	0.07285	0.22285	13.727	4.487	8
9	3.5179	0.2843	0.05957	0.29057	16.786	4.772	9
10	4.0456	0.2472	0.04925	0.19925	20.304	5.019	10
11	4.6524	0.2149	0.04107	0.19107	24.349	5.234	11
12	5.3503	0.1869	0.03448	0.18448	29.002	5.421	12
13	6.1528	0.1625	0.02911	0.17911	34.352	5.583	13
14	7.0757	0.1413	0.02469	0.17569	40.505	5.724	14
15	8.1371	0.1229	0.02102	0.17102	47.580	5.847	15
16	9.3576	0.1069	0.01795	0.16795	55.717	5.954	16
17	10.7613	0.0929	0.01537	0.16537	65.075	6.047	17
18	12.3755	0.0808	0.01319	0.16319	75.836	6.128	18
19	14.2318	0.0703	0.01134	0.16134	88.212	6.198	19
20	16.3665	0.0611	0.00976	0.15976	102.444	6.259	20
21	18.8215	0.0531	0.00842	0.15842	118.810	6.312	21
22	21.6447	0.0462	0.00727	0.15727	137.632	6.359	22
23	24.8915	0.0402	0.00628	0.15628	159.276	6.399	23
24	28.6252	0.0349	0.00543	0.15543	184.168	6.434	24
25	32.9190	0.0304	0.00470	0.15470	212.793	6.464	25
26	37.8568	0.0264	0.00407	0.15407	245.712	6.491	26
27	45.5353	0.0230	0.00353	0.15353	283.569	6.514	27
28	50.0656	0.0200	0.00306	0.15306	327.104	6.534	28
29	57.5755	0.0174	0.00265	0.15265	377.170	6.551	29
30	66.2118	0.0151	0.00230	0.15230	434.745	6.566	30
31	76.1435	0.0131	0.00200	0.15200	500.957	6.579	31
32	87.5651	0.0114	0.00173	0.15173	577.100	6.591	32
33	100.6998	0.0099	0.00150	0.15150	664.666	6.600	33
34	115.8048	0.0086	0.00131	0.15131	765.365	6.609	34
35	133.1755	0.0075	0.00113	0.15113	881.170	6.617	35
40	267.8635	0.0037	0.00056	0.15056	1779.090	6.642	40
45	538.7693	0.0019	0.00028	0.15028	3585.128	6.654	45
50	1083.6574	0.0009	0.00014	0.15014	7217.716	6.661	50

TABLE C-6 20% DISCOUNT FACTORS

n	Compound amount factor SCA	Present worth factor SPW	Sinking fund factor USF	Capital recovery factor UCR	Compound amount factor UCA	Present worth factor UPW	n
1	2	3	4	5	6	7	n
1	1.2000	0.8333	1.00000	1.20000	1.000	0.833	1
2	1.4400	0.6944	0.45455	0.65455	2.200	1.528	2
3	1.7280	0.5787	0.27473	0.47473	3.640	2.106	3
4	2.0736	0.4823	0.18629	0.38629	5.368	2.589	4
5	2.4883	0.4019	0.13438	0.33438	7.442	2.991	5
6	2.9860	0.3349	0.10071	0.30071	9.930	3.326	6
7	3.5832	0.2791	0.07742	0.27742	12.916	3.605	7
8	4.2998	0.2326	0.06061	0.26061	16.499	3.837	8
9	5.1598	0.1938	0.04808	0.24808	20.799	4.031	9
10	6.1917	0.1615	0.03852	0.23852	25.959	4.192	10
11	7.4301	0.1346	0.03110	0.23110	32.150	4.327	11
12	8.9161	0.1122	0.02526	0.22526	39.581	4.439	12
13	10.6993	0.0935	0.02062	0.22062	48.497	4.533	13
14	12.8392	0.0779	0.01689	0.21689	59.196	4.611	14
15	15.4070	0.0649	0.01388	0.21388	72.035	4.675	15
16	18.4884	0.0541	0.01144	0.21144	87.442	4.730	16
17	22.1861	0.0451	0.00944	0.20944	105.931	4.775	17
18	26.6233	0.0376	0.00781	0.20781	128.117	4.812	18
19	31.9480	0.0313	0.00646	0.20646	154.740	4.844	19
20	38.3376	0.0261	0.00536	0.20536	186.688	4.870	20
21	46.0051	0.0217	0.00444	0.20444	225.026	4.891	21
22	55.2061	0.0181	0.00369	0.20369	271.031	4.909	22
23	66.2474	0.0151	0.00307	0.20307	326.237	4.925	23
24	79.4968	0.0126	0.00255	0.20255	392.484	4.937	24
25	95.3962	0.0105	0.00212	0.20212	471.981	4.949	25
26	114.4755	0.0087	0.00176	0.20176	567.377	4.956	26
27	137.3706	0.0073	0.00147	0.20147	681.853	4.964	27
28	164.8447	0.0061	0.00122	0.20122	819.223	4.970	28
29	197.8136	0.0051	0.00102	0.20102	984.068	4.975	29
30	237.3763	0.0042	0.00085	0.20085	1181.882	4.979	30
31	284.8516	0.0035	0.00070	0.20070	1419.258	4.982	31
32	341.8219	0.0029	0.00059	0.20059	1704.109	4.985	32
33	410.1863	0.0024	0.00049	0.20049	2045.931	4.988	33
34	492.2235	0.0020	0.00041	0.20041	2456.118	4.990	34
35	590.6682	0.0017	0.00034	0.20034	2948.341	4.992	35
40	1469.7716	0.0007	0.00014	0.20014	7343.858	4.997	40
45	3657.2620	0.0003	0.00005	0.20005	18281.310	4.999	45
50	9100.4382	0.0001	0.00002	0.20002	45497.191	4.999	50

APPENDIX D

UPW FACTORS MODIFIED FOR ENERGY PRICE ESCALATION

TABLE D-1 8% UPW* DISCOUNT FACTORS

Rate of Energy Price Escalation

Year	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
1	0.9352	0.9444	0.9537	0.9630	0.9722	0.9815	0.9907	1	1.0093	1.0185
2	1.8098	1.8364	1.8633	1.8903	1.9174	1.9448	1.9723	2	2.0279	2.0559
3	2.6276	2.6788	2.7307	2.7832	2.8364	2.8903	2.9448	3	3.0559	3.1125
4	3.3925	3.4745	3.5580	3.6431	3.7298	3.8182	3.9083	4	4.0935	4.1887
5	4.1078	4.2259	4.3470	4.4711	4.5985	4.7290	4.8628	5	5.1406	5.2847
6	4.7768	4.9356	5.0994	5.2685	5.4429	5.6229	5.8085	6	6.1975	6.4011
7	5.4023	5.6058	5.8170	6.0363	6.2640	6.5003	6.7455	7	7.2641	7.5382
8	5.9874	6.2388	6.5014	6.7757	7.0622	7.3614	7.6738	8	8.3406	8.6983
9	6.5345	6.8367	7.1541	7.4877	7.8382	8.2065	8.5935	9	9.4271	9.8759
10	7.0461	7.4013	7.7766	8.1734	8.5923	9.0360	9.5046	10	10.5237	11.0773
11	7.5246	7.9346	8.3703	8.8336	9.3263	9.8502	10.4074	11	11.6304	12.3009
12	7.9726	8.4382	8.9365	9.4694	10.0394	10.6492	11.3017	12	12.7473	13.5472
13	8.3906	8.9138	9.4765	10.0817	10.7328	11.4335	12.1878	13	13.8746	14.8166
14	8.7819	9.3631	9.9915	10.6712	11.4069	12.2033	13.0657	14	15.0123	16.1095
15	9.1479	9.7873	10.4826	11.2390	12.0622	12.9588	13.9355	15	16.1606	17.4264
16	9.4902	10.1880	10.9510	11.7857	12.6994	13.7003	14.7972	16	17.3195	18.7676
17	9.8103	10.5665	11.3977	12.3121	13.3189	14.4280	15.6509	17	18.4891	20.1337
18	10.1096	10.9239	11.8237	12.8191	13.9211	15.1423	16.4967	18	19.6696	21.5250
19	10.3895	11.2615	12.2300	13.3073	14.5066	15.8434	17.3347	19	20.8610	22.9421
20	10.6513	11.5803	12.6175	13.7774	15.0759	16.5315	18.1650	20	22.0634	24.3855
21	10.8961	11.8814	12.9871	14.2301	15.6293	17.2068	18.9875	21	23.2769	25.8556
22	11.1251	12.1657	13.3395	14.6660	16.1674	17.8695	19.8025	22	24.5017	27.3529
23	11.3992	12.4343	13.6757	15.0858	16.6905	18.5202	20.6098	23	25.7378	28.8780
24	11.5894	12.6880	13.9963	15.4900	17.1991	19.1587	21.4097	24	26.9854	30.4313
25	11.7287	12.9275	14.3020	15.8792	17.6936	19.7884	22.2022	25	28.2445	32.0134

TABLE D-2 10% UPW* DISCOUNT FACTORS

Rate of Energy Price Escalation

Year	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
1	0.9182	0.9273	0.9364	0.9455	0.9546	0.9636	0.9727	0.9818	0.9909	1.0000
2	1.7612	1.7871	1.8131	1.8393	1.9657	1.8921	1.9188	1.9457	1.9727	2.0000
3	2.5353	2.5844	2.6340	2.6844	2.7354	2.7869	2.8391	2.8921	2.9456	3.0000
4	3.2460	3.4027	3.4027	3.4834	3.5656	3.6492	3.7344	3.8213	3.9097	4.0000
5	3.8986	4.0092	4.1225	4.2388	4.3581	4.4801	4.6053	4.7336	4.8650	5.0000
6	4.4978	4.6449	4.7966	4.9531	5.1146	5.2808	5.4524	5.6294	5.8117	6.0000
7	5.0480	5.2344	5.4278	5.6284	5.8367	6.0524	6.2765	6.5089	6.7498	7.0000
8	5.5521	5.7810	6.0188	6.2669	6.5260	6.7959	7.0780	7.3723	7.6793	8.0000
9	6.0159	6.2878	6.5722	6.8705	7.1839	7.5124	7.8577	8.2201	8.6004	9.0000
10	6.4417	6.7577	7.0903	7.4411	7.8118	8.2028	8.6161	9.0524	9.5130	10.0000
11	6.8328	7.1935	7.5755	7.9807	8.4113	8.8682	9.3539	9.8696	10.4174	11.0000
12	7.1919	7.5977	8.0299	8.4909	8.9837	9.5095	10.0717	10.6722	11.3138	12.0000
13	7.5216	7.9725	8.4553	8.9733	9.5300	10.1274	10.7698	11.4601	12.2020	13.0000
14	7.8243	8.3199	8.8536	9.4293	10.0513	10.7227	11.4487	12.2335	13.0819	14.0000
15	8.1022	8.6421	9.2266	9.8604	10.5490	11.2964	12.1092	12.9929	13.9539	15.0000
16	8.3574	8.9408	9.5758	10.2680	11.0240	11.8492	12.7516	13.7384	14.8178	16.0000
17	8.5918	9.2179	9.9029	10.6535	11.4776	12.3821	13.3767	14.4706	15.6742	17.0000
18	8.8069	9.4747	10.2090	11.0177	11.9103	12.8953	13.9844	15.1891	16.5223	18.0000
19	9.0044	9.7129	10.4957	11.3622	12.3235	13.3900	14.5757	15.8947	17.3630	19.0000
20	9.1857	9.9337	10.7641	11.6878	12.7178	13.8666	15.1507	16.5873	18.1958	20.0000
21	9.3512	10.1385	11.0154	11.9957	13.0942	14.3259	15.7101	17.2674	19.0211	21.0000
22	9.5042	10.3285	11.2509	12.2870	13.4537	14.7688	16.2546	17.9355	19.8394	22.0000
23	9.6446	10.5046	11.4714	12.5623	13.7968	15.1955	16.7841	18.5913	20.6501	23.0000
24	9.7735	10.6679	11.6777	12.8225	14.1241	15.6065	17.2989	19.2349	21.4531	24.0000
25	9.8919	10.8193	11.8710	13.0686	14.4367	16.0026	17.7998	19.8670	22.2490	25.0000

TABLE D-3 12% UPW* DISCOUNT FACTORS

Rate of Energy Price Escalation

Year	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
1	0.9018	0.9107	0.9196	0.9286	0.9375	0.9464	0.9554	0.9643	0.9732	0.9822
2	1.7150	1.7401	1.7654	1.7908	1.8164	1.8422	1.8681	1.8941	1.9204	1.9468
3	2.4484	2.4955	2.5432	2.5915	2.6404	2.6899	2.7400	2.7908	2.8421	2.8941
4	3.1097	3.1834	3.2585	3.3349	3.4129	3.4922	3.5731	3.6554	3.7392	3.8246
5	3.7061	3.8099	3.9163	4.0253	4.1371	4.2516	4.3690	4.4891	4.6123	4.7384
6	4.2438	4.3804	4.5212	4.6664	4.8160	4.9702	5.1292	5.2931	5.4620	5.6360
7	4.7288	4.9000	5.0775	5.2616	5.4525	5.6504	5.8556	6.0683	6.2889	6.5175
8	5.1662	5.3732	5.8292	5.8144	6.0492	6.2941	6.5495	6.8159	7.0936	7.3832
9	5.5606	5.8042	6.0597	6.3276	6.6086	6.9034	7.2125	7.5368	7.8768	8.2335
10	5.9162	6.1967	6.4924	6.8042	7.1331	7.4800	7.8459	8.2319	8.6391	9.0686
11	6.2370	6.5541	6.8903	7.2468	7.6248	8.0257	8.4510	8.9022	9.3809	9.8888
12	6.5262	6.8796	7.2563	7.6577	8.0857	8.5422	9.0291	9.5485	10.1028	10.6944
13	6.7870	7.1761	7.5928	8.0393	8.5179	9.0310	9.5813	10.1718	10.8054	11.4856
14	7.0222	7.4461	7.9023	8.3936	8.9230	9.4936	10.1089	10.7728	11.4892	12.2626
15	7.2343	7.6920	8.1870	8.7227	9.3028	9.9315	10.6130	11.3523	12.1547	13.0258
16	7.4256	7.9159	8.4487	9.0282	9.6589	10.3458	11.0946	11.9112	12.8023	13.7753
17	7.5981	8.1198	8.6895	9.3119	9.9927	10.7380	11.5546	12.4501	13.4326	14.5115
18	7.7536	8.3056	8.9108	9.5753	10.3057	11.1092	11.9942	12.9697	14.0460	15.2345
19	7.8939	8.4747	9.1144	9.8200	10.5991	11.4605	12.4141	13.4708	14.6430	15.9446
20	8.0204	8.6288	9.3017	10.0471	10.8741	11.7930	12.8152	13.9540	15.2240	16.6420
21	8.1345	8.7691	9.4739	10.2580	11.1320	12.1076	13.1985	14.4199	15.7894	17.3270
22	8.2373	8.8968	9.6322	10.4539	11.3737	12.4054	13.5646	14.8692	16.3397	17.9997
23	8.3301	9.0132	9.7778	10.6357	11.6004	12.6873	13.9144	15.3024	16.8752	18.6604
24	8.4137	9.1191	9.9118	10.8046	11.8129	12.9540	14.2486	15.7202	17.3964	19.3093
25	8.4892	9.2156	10.0349	10.9614	12.0121	13.2065	14.5678	16.1231	17.9037	19.9467

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Energy conservation in buildings has become critical in the planning and design of buildings due to increasing energy prices and the threat of fuel shortages. Architects, engineers, builders, and others concerned with the design and operation of buildings need principles and guidelines for making economically efficient investment decisions in energy conservation. This guidebook provides principles, techniques, step-by-step illustrations, and sample problems on how to evaluate the economics of energy conservation and solar energy investments. Techniques of economic evaluation including life-cycle costing, net benefits, savings-to-investment ratio, internal rate-of-return, and discounted payback analyses are described and compared in terms of their advantages and disadvantages. Discounting, a procedure for taking into account the time value of money, is illustrated in the analysis of an investment in heat pumps. Practice problems for discounting and for applying each of the five techniques are presented. Factors that affect benefits and costs, including time horizons, discount rates, inflation, incentives, taxes, salvage values, and measures of uncertainty, are discussed, and guidance is provided for selecting appropriate values for these factors when making economic evaluations. Comprehensive case illustrations for solar heating and for window design management are described. Appendices provide tables and formulae for evaluating the economics of alternative conservation investments.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Benefit cost; building economics; discounting; economic analysis; economic efficiency; energy conservation; incentives; life-cycle cost; payback; rate of return; solar economics; windows.

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