U.S. Department of Commerce
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
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Recommended Practice for Measuring Benefit/Cost and Savings-to-Investment Ratios for Buildings and Building Systems

Harold E. Marshall
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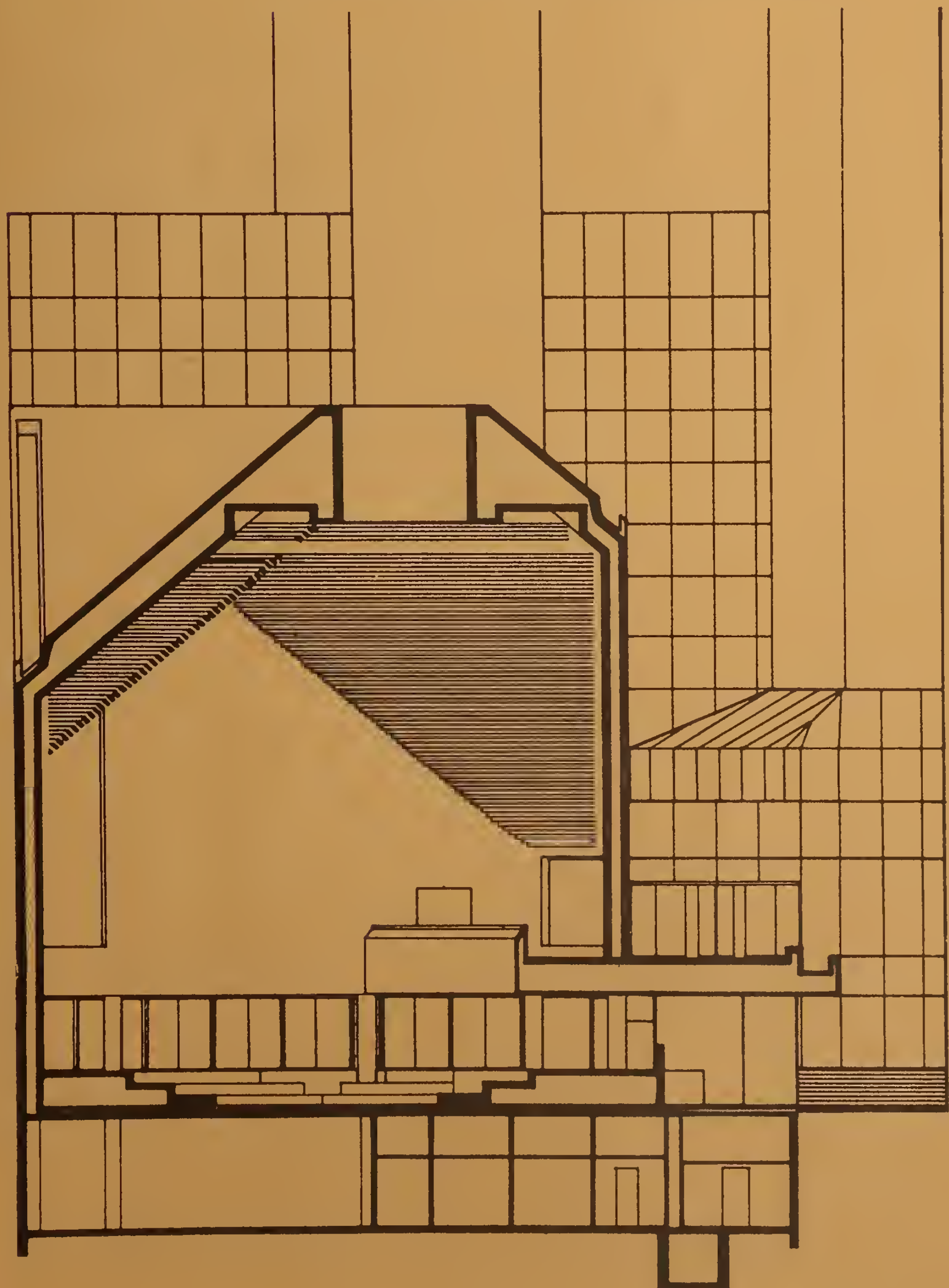
November 1981



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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, ***Secretary***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

ABSTRACT

This report describes how to calculate a benefit-cost ratio (B/C) and a savings-to-investment ratio (SIR) and how to use them in selecting building designs and building systems that will be cost effective in the long run. The B/C relates positive benefits, such as revenues, to project costs in the form of a ratio. The SIR, a variation of the B/C, relates project savings (i.e., cost reductions) to project costs in a ratio. It is used when there are few if any positive cash flows from a project. The B/C and SIR can be used to help answer such questions as: "Is a project cost effective?" "Which size and/or design of a project is most cost effective?" "What priorities should be given individual projects competing for a limited budget?" The report addresses different formulations of the ratios and their implications for selecting cost-effective projects.

PREFACE

The benefit-cost ratio (B/C) and a variation thereof, the savings-to-investment ratio (SIR), are economic evaluation tools that compare discounted positive and negative cash flows in the form of a ratio. These tools are useful in determining if projects are economically worthwhile, in designing and sizing projects, and in deciding project priorities.

Decreasing productivity in the construction industry coupled with rising costs of labor, material, and energy have prompted builders, architects, engineers, building owners and operators, and code writers to turn increasingly to economic evaluation techniques, including the B/C or SIR method, to identify building designs and building systems that will be cost effective in the long run. A practical, standardized approach for calculating the B/C and SIR for building decisions is needed.

This report has been prepared by the National Bureau of Standards (NBS) in support of an ongoing standards development activity in the American Society of Testing and Materials (ASTM E-6, Performance of Building Constructions) and in response to requests from the building community for assistance in applying economic analysis in a uniform and practicable manner. This document has been submitted to ASTM E-6.81, the Building Economics Subcommittee, for its consideration in the development of a "Recommended Practice for Calculating Benefit-Cost and Savings-to-Investment Ratios for Buildings and Building Systems." It is the second NBS report to be submitted to ASTM E-6.81, and builds in part upon the definitions and techniques (such as discounting) described in the first report, entitled Recommended Practice for Measuring Life-Cycle Costs of Buildings and Building Systems.[1]

This report describes how to calculate the B/C and SIR and illustrates their uses. A detailed discussion of alternative formulations of the ratios and of their respective strengths and weaknesses is presented because the report is intended in part as a working aid for the subcommittee members developing the standard. Specifically, it provides the technical base for the development by the subcommittee of a standard method or recommended practice for calculating B/C and SIR for investments in buildings and building systems. Applying a standardized B/C and SIR method to building design and investment decisions will help to assure that the cost effectiveness of alternative building projects can be compared in a consistent and technically correct manner.

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[1] Rosalie T. Ruegg, Stephen R. Petersen, and Harold E. Marshall, Recommended Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, National Bureau of Standards Interagency Report 80-2040, June 1980.

The preparation of this report is one of a series of steps towards producing a comprehensive set of standard recommended economic practices that will meet the diverse needs of the building community for measures of economic performance. Future reports will address other economic evaluation techniques used in building decisions, including the internal rate of return technique and the payback technique.

Thanks are due the members of ASTM who have participated in the Building Economics Subcommittee meetings and thereby have helped determine the framework of this paper. Thanks are also due our colleagues at the National Bureau of Standards who assisted in the preparation of this report. Special appreciation is extended to Stephen Weber, Fred Stahl, James Pielert, Robert Chapman, Stefan Leigh, Barbara Lippiatt, Laurene Linsenmayer, and Ulesia Gray.

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1. INTRODUCTION

The benefit-cost ratio (B/C) and a variation thereof, the savings-to-investment ratio (SIR), are part of a family of economic evaluation techniques that provide measures of economic performance of an investment over some period of time extending into the future. This family of techniques includes, in addition to B/C and SIR, the techniques of net benefits analysis, internal rate-of-return analysis, life-cycle cost analysis, and payback analysis.[1]

The B/C and SIR are the focus of this report, the second in a series of National Bureau of Standards (NBS) reports on recommended practices for applying economic evaluation techniques to building decisions. The life-cycle cost technique was the topic of the first report in the NBS series, entitled Recommended Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, NBSIR 80-2040. Future publications are planned for the internal rate-of-return and payback techniques to complete a comprehensive package of recommended practices for economic analysis of buildings and building systems.

The B/C and SIR are numerical ratios which indicate the economic value of a project by the size of the ratio. A ratio of less than one indicates a project that is uneconomical; a ratio of one indicates a project whose benefits or savings just equal its costs; and a ratio greater than one indicates an economical project. The larger the ratio, the more the dollar benefits or savings exceed project costs. The B/C is used when the focus is on positive benefits, such as revenues, relative to project costs. The SIR, a variation of the B/C ratio, is used when the focus is on project savings (i.e., cost reductions) relative to project costs. Issues to be addressed in this report in addition to the formulation of

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[1] For a general treatment of these techniques, see a benefit-cost or engineering economics textbook, such as E. J. Mishan, Cost-Benefit Analysis; An Introduction (New York, New York: Praeger Publishers, 1971), or Gerald W. Smith, Engineering Economy: Analysis of Capital Expenditures (Ames, Iowa: The Iowa State University Press, 1973). For a specific treatment of these techniques applied to energy conservation and renewable energy in buildings, see one of the following: Harold E. Marshall and Rosalie T. Ruegg, Simplified Energy Design Economics: Principles of Economics Applied to Energy Conservation and Solar Energy Investments in Buildings, National Bureau of Standards Special Report 544, January 1980; Harold E. Marshall and Rosalie T. Ruegg, Energy Conservation in Buildings: An Economics Guidebook for Investment Decisions, National Bureau of Standards Handbook 132, May 1980; Rosalie T. Ruegg, Life-Cycle Costing Manual for the Federal Energy Management Programs, National Bureau of Standards Handbook 135, December 1980; and Rosalie T. Ruegg et al., Life-Cycle Costing: A Guide for Selecting Energy Conservation Projects for Public Buildings, National Bureau of Standards Building Science Series 113, September 1978.

the ratios are their application to accept-reject decisions, to sizing and design problems, and to setting priorities among independent projects competing for limited resources.

1.1 SCOPE AND ORGANIZATION

This report establishes a technical base for the development of a recommended practice for calculating and interpreting the B/C and SIR of building designs and systems. Sections 2 through 6 set forth the procedural framework within which the B/C or SIR technique is applicable. Section 2 identifies the objectives, alternatives, and constraints for a B/C or SIR evaluation. Section 3 lists assumptions typically required for calculating the B/C or SIR and suggests guidelines for selecting parametric values to be used in the calculation. Section 4 identifies major categories of benefits, savings, and costs typically treated in B/C and SIR evaluations. Section 5 introduces "discounting" for converting cash flows spread over time to their equivalent values at a common time, and provides discounting formulas.[1] Section 6 discusses issues regarding the formulation of the B/C and SIR and gives recommended calculation procedures. Special attention is given the placement of benefit and cost items in the ratios because varied placement can alter the ratios and bias the results. Section 7 explains the use of the B/C or SIR in different kinds of applications, such as to accept or reject a project, to allocate limited investment funds among competing projects, and to size and design a project. Appendix A illustrates the solution to a sample building investment problem by the SIR technique. Selected references conclude the report in appendix B.

1.2 PROCEDURES FOR B/C AND SIR EVALUATION

The recommended framework for using the B/C and SIR techniques to evaluate a building design, project, or investment decision can be summarized in five procedural steps:

1. Identify Objectives, Alternatives, and Constraints,
2. Establish Assumptions,
3. Compile Data,
4. Discount Cash Flows to a Comparable Time Basis, and
5. Compute B/C or SIR and Compare Alternatives.

In sections 2 through 6, each of these steps is addressed further.

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[1] The first report in this series, Recommended Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, discusses discounting, inflation, uncertainty, and other topics that are equally relevant to the B/C and SIR techniques as to the life-cycle costing technique. The earlier report is cited where appropriate.

2. IDENTIFY OBJECTIVES, ALTERNATIVES, AND CONSTRAINTS

First, the problem to be addressed by the B/C or SIR technique should be clearly specified. This entails identifying the objective of the investor or decision maker, as well as any constraints to the achievement of the objective. Alternative approaches to reaching that objective within the designated constraints are then identified.

An example of a building investment problem that could be evaluated with the B/C technique is choosing the locations for new stores in a national chain. The objective is to maximize profits or net benefits from investments in new stores. The alternatives are the different locations where stores might be built. The constraint is that there is only enough investment capital for a few stores, whereas stores in many locations would likely yield profits. The B/C technique will guide the decision maker to those store locations where net benefits per investment dollar will be maximized.

An example of a problem that could be evaluated with an SIR is selecting retrofit options for conserving energy in an existing building. The objective is to select that combination of options that maximizes net savings for the available budget. Alternatives might include attic insulation, weatherstripping, installing a heat pump, adding storm windows, or a combination thereof. A limited dollar budget for energy conservation is the investment constraint. The SIR technique will guide the decision maker to that combination of retrofit options that will maximize net savings from investing the conservation budget.

3. ESTABLISH ASSUMPTIONS

A number of assumptions usually must be made in order to perform an economic evaluation of a design or investment problem. The solution to a problem may vary considerably depending on the assumptions. To arrive at realistic solutions, it is important to select carefully the assumed values for critical parameters. Sensitivity analysis can be used to identify the critical parameters in a given problem and to test the outcome for a range of values of those parameters.

Assumptions that are often significant in applying the B/C or SIR technique concern the study period over which the evaluation is to be made, the value of the discount rate, the level of taxes, and the rate of inflation. General guidelines for selecting values for these parameters are found in Recommended Practice for Measuring Life-Cycle Costs of Buildings and Building Systems and elsewhere,[1] and will not be discussed here.

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[1] Ruegg, Petersen, and Marshall, Recommended Practice for Measuring Life-Cycle Costs, pp. 9-11; Marshall and Ruegg, Simplified Energy Design Economics, pp. 27-34; and Marshall and Ruegg, Energy Conservation in Buildings: An Economics Guidebook, pp. 1-42.

4. COMPILE DATA

For calculating a B/C or SIR for alternative building designs, building systems, or building practices, typical cost categories for which data will be needed are a) investment costs, including the costs of planning, design, engineering, construction, purchase, installation, and financing; b) non-fuel operating and maintenance costs, including the materials and labor costs for routine upkeep and operation other than energy; c) repair and replacement costs, including future costs to repair or replace a building system or component that wears out, fails, or is damaged, and related costs, such as design costs for the replacement and insurance costs less reimbursements; d) energy costs; and e) property and capital gains taxes. Data will also be needed for any positive dollar benefits, such as income or revenue, resale values, and cash grants, as well as for any cost-reducing items, such as energy or maintenance cost savings, tax deductible expenses, and tax credits. Other data requirements are income tax rates, discount rates, depreciation methods and periods, and financing terms. Data may be compiled from published and unpublished sources, they may be estimated, or they may be assumed.[1]

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[1] Ruegg's Life-Cycle Cost Manual for the Federal Energy Management Program has a chapter on "Data and Assumptions" (pp. 37-48) and lists some projections of energy prices in appendix C. See Carol Chapman Rawie, Estimating Benefits and Costs of Building Regulations: A Step by Step Guide, National Bureau of Standards Report 81-2223, June 1981, the end of chapters 1-3, for listings of sources of information on data relating to economic analyses of buildings.

5. CONVERSION OF CASH AMOUNTS TO A COMMON TIME BASIS

Once the pertinent data have been collected, all cash amounts must be converted to a common time basis, i.e., discounted to time-equivalent present values or annual values. This conversion of amounts to time-equivalent values (often called "discounting") is performed by applying discount formulas, or corresponding discount factors calculated from those formulas, to the estimated benefit and cost data associated with a given design or investment alternative. The discount formulas incorporate the "discount rate," a rate of return which should reflect the investor's opportunity cost; i.e., the rate of return available on the next best alternative investment. Similarly, discount factors are based on specific discount rates. Table 5.1 lists the most commonly used discount formulas, indicates their use, and gives their algebraic form. Discount factors calculated for alternative discount rates are published in many textbooks on benefit-cost analysis and engineering economics.[1]

The first step in the time-equivalency conversion is to select a common time to which all cash amounts are adjusted--either (1) the present, whereby all cash amounts are converted to an equivalent value occurring now, i.e., to a present value, or (2) annually, whereby all cash amounts are converted to a time-equivalent value occurring in a uniform amount each year over the study period, i.e., to an annual value. Then the appropriate formula or factor, incorporating the investor's opportunity cost as indicated by the discount rate, is applied to each cash amount to convert it to its equivalent value at a selected time. The case example in appendix A illustrates the process.[2]

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[1] See, for example, Smith, Engineering Economy: Analysis of Capital Expenditures. A set of discount factors based on the formulas shown in table 5.1 and including the UPW* factors for a range of escalation rates can be found in Marshall and Ruegg, Energy Conservation in Buildings: An Economics Guidebook, and a set of discount factors including UPW* factors based on the U.S. Department of Energy energy price escalation rates by region of the U.S. and by type of fuel can be found in Ruegg, Life-Cycle Cost Manual for the Federal Energy Management Program, appendix B.

[2] Step-by-step procedures for discounting are found in Marshall and Ruegg, Simplified Energy Design Economics, pp. 16-20. For a discussion of how to handle inflation in discounting, see Recommended Practice for Measuring Life-Cycle Costs, pp. 14-15.

TABLE 5.1 DISCOUNT FORMULAS

Formula Name	Illustration	Use	Algebraic Form
Single Compound Amount Formula (SCA)	[P] → [F?]	To find F when P is known	$F = P \cdot (1 + i)^N$
Single Present Value Formula (SPW)	[P?] ← [F]	To find P when F is known	$P = F \cdot \frac{1}{(1 + i)^N}$
Uniform Sinking Fund Formula (USF)	[A?] + [A?] · · [A?] → [F]	To find A when F is known	$A = F \cdot \frac{1}{(1 + i)^N - 1}$
Uniform Capital Recovery Formula (UCR)	[P] → [A?] + [A?] · · · · [A?]	To find A when P is known	$A = P \cdot \frac{i(1 + i)^N}{(1 + i)^N - 1}$
Uniform Compound Amount Formula (UCA)	[A] + [A] · · [A] → [F?]	To find F when A is known	$F = A \cdot \frac{(1 + i)^N - 1}{i}$
Uniform Present Value Formula (UPW)	[P?] ← [A] + [A] · · · · [A]	To find P when A is known	$P = A \cdot \frac{(1 + i)^N - 1}{i(1 + i)^N}$
Uniform Present Value Formula Modified (UPW*)	[P?] ← [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 for the period being considered.

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

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

$$P = A \sum_{j=1}^{n_1} \left(\frac{1 + e_1}{1 + i}\right)^j + \left(\frac{1 + e_1}{1 + i}\right)^{n_1} \sum_{j=1}^{n_2} \left(\frac{1 + e_2}{1 + i}\right)^j + \ldots$$

$$+ \left(\frac{1 + e_1}{1 + i}\right)^{n_1} \left(\frac{1 + e_2}{1 + i}\right)^{n_2} \cdots \left(\frac{1 + e_{k-1}}{1 + i}\right)^{n_{k-1}} \sum_{j=1}^{n_k} \left(\frac{1 + e_k}{1 + i}\right)^k$$

where n_h = the length of the period for a given escalation rate in a given period, and the subscript h = the escalation period, and

$$\sum_{j=1}^{n_h} \left(\frac{1 + e_h}{1 + i}\right)^j = \left(\frac{1 + e_h}{i - e_h}\right)\left(1 - \left(\frac{1 + e_h}{1 + i}\right)^{n_h}\right)$$

6. COMPUTE B/C OR SIR AND COMPARE ALTERNATIVES

After all cash amounts relevant to a given investment have been discounted to present or annual values, they can be used to calculate the B/C or SIR. Although the concept of the B/C and SIR is simple, there is some controversy regarding their formulation. The difficulty arises when a project involves costs and benefits that are subject to varying interpretation regarding placement in the numerator or denominator of the ratios. The formulation is important because changes in the ratios can be induced by changing the placement of cost and benefit items, and biasing effects detrimental to economic efficiency can result.[1]

Changing the placement of items from the numerator to the denominator of the B/C or SIR will not cause a project which appears cost effective by one version of the ratio to appear uneconomical by a different version.[2] The placement, however, can affect the numerical value of a ratio for a given project. Moreover, the placement can affect the relative values of ratios for different projects and, thereby, their priority ranking.

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[1] For projects that give rise to a single kind of cost, such as an initial investment for purchase and installation, there is no choice in the formulation of the ratio and no biasing effects to consider.

[2] The following proof shows that changing the placement of items from the numerator to the denominator will not cause a project which is cost effective by one measure to be cost ineffective by another.

Given: $\frac{B - O - M - R + V}{I} > 1$ prove $\frac{B}{I + O + M + R - V} > 1$.

Proof: If $\frac{B - O - M - R + V}{I} > 1$, then

$B - O - M - R + V > I$,

$B > I + O + M + R - V$, and therefore, since $I + O + M + R - V >$ zero,

$\frac{B}{I + O + M + R - V} > 1$. Hence, if benefits (or savings) exceed costs under one formulation of the ratio, they will also exceed them under the other formulation. (Variables are defined in the text, under equation 6.1.)

Table 6.1 shows the direction of change of the B/C and SIR (i.e., whether the ratio increases or decreases) as a function of placement of given cost or salvage items in the ratio formulations. The cost items--operation, maintenance, and replacement--and salvage value appear in the left hand column. The items may increase or decrease as a result of an investment. The second column of table 6.1 indicates all possible placements in the denominator or numerator of both positive and negative cost and salvage items. The third column indicates by means of arrows and dashes whether the ratios increase (↑), decrease (↓), or remain unchanged (--) when the placement is changed for any given item; that is, when an item is transferred from the denominator (numerator) to the numerator (denominator). Since the direction of the change in the ratio varies depending on the value of the ratio before the change in placement i.e., whether the ratio is >, =, or <1, subcolumns are provided for each of the three possible cases.

An example from the table will help illustrate how a change in placement can affect the B/C and SIR. For a ratio greater than one, the value of the ratio will be higher if a savings in operating cost is subtracted from other costs in the denominator rather than added to other savings or benefits in the numerator. Row three shows further that, if the ratio had previously been equal to one, the ratio would have remained the same regardless of the placement of the savings in operating costs, and if the ratio had been less than one, it would be lower if the savings were subtracted from the denominator.[1]

Since the ratio values may vary depending on the placement of cost and salvage items, thereby influencing the investment decision, it is important to select a formulation for the ratio that best satisfies the investor's objective. The remainder of this chapter identifies alternative formulations of the B/C and SIR that are commonly used, identifies the biases that appear to be inherent in some of the formulations, and determines which formulations are appropriate for different investment objectives.

Differences in B/C and SIR formulations involve differences in the placement of operating costs (O), maintenance costs (M), replacement cost (R), and salvage value (V). Equations 6.1 through 6.8, presented below, depict the most widely used versions of the ratios. In equations 6.1 and 6.2 all costs and salvage appear in the denominator. Equations 6.3 through 6.8 differ in that items other than benefits and savings appear in the numerator.[2]

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[1] Table 6.2 gives numerical examples that illustrate the direction of changes in the ratios described in table 6.1.

[2] A discussion of B/C formulations is contained in Smith, Engineering Economy, Chapter 11. (Smith does not address the treatment of replacement costs and salvage value.)

TABLE 6.1 DIRECTION OF CHANGE IN B/C OR SIR INDUCED BY ALTERNATIVE PLACEMENT OF OPERATING (O), MAINTENANCE (M), AND REPLACEMENT (R) COSTS AND SALVAGE (V) VALUE

Costs and Salvage Items	Placement of Cost Item	Direction of Change of Ratios B/C SIR > 1	B/C SIR = 1	B/C SIR < 1
Increase in O, M, and/or R Cost and/or Decrease in V Value	Denominator	↓	--	↑
	Numerator	↑	--	↓
Decrease in O, M, and/or R Cost and/or Increase in V Value	Denominator	↑	--	↓
	Numerator	↓	--	↑

Notation: ↓ indicates B/C or SIR is lower than it would be with the alternative placement.
↑ indicates B/C or SIR is higher than it would be with the alternative placement.
-- indicates B/C or SIR is unchanged by the choice of placement.

The equations are presented in pairs, the odd numbered equations giving the B/C and the sequential, even numbered equation, the counterpart SIR.[1]

$$B/C = \frac{B}{I + O + M + R - V}, \quad (6.1)$$

$$SIR = \frac{S}{I + O + M + R - V}, \quad (6.2)$$

where B = present value benefits such as revenue or other positive effects,

I = present value investment costs of the project,

O = present value operating costs, including energy costs associated with the project,

M = present value maintenance costs,

R = present value replacement costs,

V = present value resale or residual value resulting from disposal of assets,

S = cost reductions resulting from the project.

$$B/C = \frac{B + V}{I + O + M + R}, \quad (6.3)$$

and

$$SIR = \frac{S + V}{I + O + M + R}, \quad (6.4)$$

where variables are as defined above.

$$B/C = \frac{B - O - M}{I + R - V}, \quad (6.5)$$

and

$$SIR = \frac{S - O - M}{I + R - V}, \quad (6.6)$$

where variables are as defined above.

$$B/C = \frac{B - O - M - R + V}{I}, \quad (6.7)$$

and

$$SIR = \frac{S - O - M - R + V}{I}, \quad (6.8)$$

where variables are as defined above.

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[1] For the purpose of exposition, it is assumed that all amounts are already in present value or annual value dollars. Thus the discounting operation is not shown in the equations.

Most other versions of the B/C or SIR that one encounters in the financial analysis literature and in application are equivalent to one of the above formulations.[1]

To analyze the equations for bias, it is necessary to have an efficiency criterion. The criterion proposed in this study is the maximization of net benefits (NB) for the available investment budget, where the budget can be specified for the current year or a multi-year planning period. Net benefits are the difference between benefits and costs, evaluated in present or annual value dollars. Equations 6.7 and 6.8 are the only equations that consistently satisfy this criterion. Calculations based on either of these equations will lead to the selection of designs, sizes, or combinations of projects that satisfy the efficiency criterion. Applying any of the other equations may under certain conditions result in a bias against cost-effective project selection. That is, their use may lead to the selection of designs, sizes, or combinations of projects which do not maximize net benefits per investment dollar. The magnitude of the bias from using equations 6.1 through 6.6 is a function of how much the B/C and SIR values are distorted from the values that would be calculated from equations 6.7 and 6.8.[2]

Table 6.2 shows B/C's calculated for a series of seven hypothetical projects. (The SIR calculations are not shown but would correspond to the counterpart B/C examples.) The purpose of the table is to show how the B/C will differ for a given investment project, depending on the formula that is used, and how the choice will affect project rankings.

To focus on the change in the ratio that may be induced by simple changes in placement of cost and benefit components, each of the projects is assumed to yield the same present value net benefits of $50,000. Projects 1 and 2 both have investment costs (I) of $50,000, but project 1 results in positive revenue (B) of $100,000, while project 2 yields $80,000 of revenue and $20,000 of reductions in operating (O) and replacement (R) costs. Projects 3 and 4 have equal B values of $100,000, but their $20,000 of maintenance (M) and replacement (R) costs are split differently. Project 5 has $95,000 of B and $5,000 of residual value (V), with $50,000 of costs made up of I, O, & R. Project 6 has the highest investment cost, but $20,000 of it is offset by O and R cost reductions. Project 7 has the largest positive and negative cash flows, but the same net benefits as the other projects.

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[1] For an industry version of the B/C equation, equivalent to equation 6.1 above, see American Telephone and Telegraph Company, Engineering Economy: A Manager's Guide to Economic Decision Making, 3rd Ed. (New York, New York: McGraw-Hill Book Company, 1977), pp. 411-412.

[2] Note that investors may prefer in some cases a formulation of the ratio that has a bias as defined here, because they may wish to maximize the return on a particular type of funds, such as current account expenditures which might be the constraining resource.

TABLE 6.2 HYPOTHETICAL PROJECTS EVALUATED WITH ALTERNATIVE FORMULATIONS OF THE B/C[a]

B/C Formula (1)	Project 1 B = \$100 M = 0 I = \$ 50 R = 0 O = 0 V = 0 NB = \$50 (2)	Project 2 B = \$ 80 M = 0 I = \$ 50 R = \$-10 O = \$-10 V = 0 NB = \$ 50 (3)	Project 3 B = \$100 M = \$20 I = \$ 30 R = 0 O = 0 V = 0 NB = \$50 (4)	Project 4 B = \$100 M = 0 I = \$ 30 R = \$20 O = 0 V = 0 NB = \$50 (5)	Project 5 B = \$ 95 M = 0 I = \$ 30 R = \$ 10 O = \$ 10 V = \$ 5 NB = \$ 50 (6)	Project 6 B = \$100 M = 0 I = \$ 70 R = \$-10 O = \$-10 V = 0 NB = \$ 50 (7)	Project 7 B = \$100 M = \$ 10 I = \$ 38 R = \$ 10 O = 0 V = \$ 8 NB = \$ 50 (8)
(Eq. 6.1) $\frac{B}{I + O + M + R - V}$	$\frac{100}{50} = 2$	$\frac{80}{50 + (-10) + (-10)} = 2.67$	$\frac{100}{30 + 20} = 2$	$\frac{100}{30 + 20} = 2$	$\frac{95}{30 + 10 + 10 - 5} = 2.11$	$\frac{100}{70 - 20} = 2$	$\frac{100}{38 + 10 + 10 - 8} = 2$
(Eq. 6.3) $\frac{B + V}{I + O + M + R}$	$\frac{100}{50} = 2$	$\frac{80}{50 + (-10) + (-10)} = 2.67$	$\frac{100}{30 + 20} = 2$	$\frac{100}{30 + 20} = 2$	$\frac{95 + 5}{30 + 10 + 10} = 2$	$\frac{100}{70 - 20} = 2$	$\frac{100 + 8}{38 + 10 + 10} = 1.86$
(Eq. 6.5) $\frac{B - O - M}{I + R - V}$	$\frac{100}{50} = 2$	$\frac{80 - (-10)}{50 + (-10)} = 2.25$	$\frac{100 - 20}{30} = 2.67$	$\frac{100}{30 + 20} = 2$	$\frac{95 - 10}{30 + 10 - 5} = 2.43$	$\frac{100 - (-10)}{70 + (-10)} = 1.83$	$\frac{100 - 10}{38 + 10 - 8} = 2.25$
(Eq. 6.7) $\frac{B - O - M - R + V}{I}$	$\frac{100}{50} = 2$	$\frac{80 - (-10) - (-10)}{50} = 2$	$\frac{100 - 20}{30} = 2.67$	$\frac{100 - 20}{30} = 2.67$	$\frac{95 - 10 - 10 + 5}{30} = 2.67$	$\frac{100 - (-10) - (-10)}{70} = 1.71$	$\frac{100 - 10 - 10 + 8}{38} = 2.32$

[a] All amounts are assumed to be in present value dollars in thousands. Projects are assumed to be independent of one another. Investment costs are assumed to occur at the outset of the project and other values in the future.

Comparing the project ratios in table 6.2 derived by each equation, one sees inconsistencies in results. Equations 6.1 and 6.3, for example, would give priority to project 2 over the other projects; equation 6.5, priority to project 3; and equation 6.7, equal priority to projects 3, 4, and 5. Equation 6.3 gives lowest priority to project 7, while equations 6.5 and 6.7 give it higher priority than some of the other projects. Each of the equations gives the same economic efficiency indicator for project 1 because it involves only one category of cost, I.

How do these differences in results among the B/C's affect the economic efficiency of project selection? Comparing projects 1 and 2, one finds not only the same investment requirements, but also the same present value of future net cash flows (i.e., revenues (B) plus cost reductions in O and R). The use of equations 6.1, 6.3, or 6.5 to choose between projects 1 and 2 would result in the selection of project 2 over 1. This occurs because the future benefits accrue in the form of cost reductions rather than revenues, and, as was shown in table 6.1, subtracting values from the denominator of a cost-effective project results in a higher ratio than adding the same values to the numerator.

Projects 3, 4, and 5 are identical to one another in terms of investment costs and benefits; they differ only in the apportionment of their future amounts among operating, maintenance, replacement costs, and salvage value. Yet only equations 6.3 and 6.7 give identical ratio values and rankings for the three projects, and their ratio values differ one from the other (2 versus 2.67).

To determine how the different formulas rate on efficiency grounds, the first three equations can be compared against equation 6.7, which best satisfies the criterion of maximizing net benefits per investment dollar. Guided by equation 6.7, the decision maker would choose projects 3, 4, and/or 5 with low initial investment requirements in favor of projects 1, 2, 6, and/or 7 with higher investment requirements. With a limited budget of $100,000 for example--and assuming independent, non-mutually exclusive projects--net benefits would be maximized by investing $30,000 each in projects 3, 4, and 5, spending $90,000 of the $100,000, and obtaining $150,000 in net benefits. This is clearly more efficient than spending the $100,000 in projects 1 and 2, as equation 6.3 might suggest, and obtaining only $100,000 in net benefits. In short, table 6.2 shows that equations 6.1, 6.3, and 6.5 (and their counterparts, equations 6.2, 6.4, and 6.6) provide unreliable indicators of a project's return on investment, because their priority rankings of projects depend on the cost composition of the projects rather than on their comparative economic efficiency. Their use may cause a decision maker to select projects that together do not meet the economic efficiency criterion of maximizing net benefits for the available investment budget.

Detailed examples of the biasing effects of using the conventional B/C and SIR equations and the economic inefficiencies that may result are illustrated further in tables 6.3 and

6.4. Table 6.3 compares equation 6.1 to equation 6.7 with respect to the economic efficiency criterion of maximizing net benefits per investment dollar. The hypothetical problem is to assign priority to the construction of three public recreation facilities designated Projects A, B, and C. For simplicity, the projects are assumed equal in their initial investment cost of $1,000 (col. 5), but different in the present value of their benefits and the level of the operating costs incurred by the public authorities. The present value of their future total cash flows, i.e., benefits less operating costs (col. 4) differ, as well as their total net benefits (col. 6). With the objective of obtaining the maximum net benefits from the expenditure of limited investment funds, the public authorities will rank the three potential recreation projects in declining order of their B/C values.

As may be seen by comparing columns 7 and 9, the B/C's for each project differ depending on which B/C formulation is used. As may be seen by comparing columns 8 and 10, the assigned priorities also differ by B/C formulation. Equation 6.1 gives first priority to Project B, while equation 6.7 indicates that Project A--the last ranked by equation 6.1--is preferred. Looking to the net benefits column (col. 6), we can see that the project rankings provided by equation 6.7 are consistent with maximizing total net benefits from the public recreation facilities budget. For example, if a budget of only $2,000 were available, equation 6.7 would indicate Projects A and C for a total net benefits of $5,500, whereas equation 6.1 would indicate projects B and C for a total net benefits of only $4,000.[1]

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[1] In the examples of tables 6.3 and 6.4, investment costs are held constant across projects, causing the project rankings produced by the net benefits measure (col. 6) to be consistent with the rankings provided by equation 6.7 and 6.8. Furthermore, with the small number of projects given in the table, one could easily arrive at the economically efficient selection of projects in the face of a budget constraint without a formal ranking device, simply by summing and comparing the net benefits of alternative combinations of projects. It should be noted, however, that when investment costs differ among projects, ranking projects in descending order of their individual net benefits may produce project rankings that are inconsistent with the rankings provided by equation 6.7. More specifically, if investment costs vary among projects, selecting projects in descending order of their individual net benefits until the budget is exhausted may not produce a selection of projects which together yield maximum total net benefits, whereas selecting projects in descending order of their ratios calculated by equations 6.7 and 6.8 will accomplish this objective, provided "lumpiness" in project costs does not prevent spending all or most of the available budget. The shortcoming of the net benefits measure for project ranking may be seen in its failure to distinguish projects that require different investment outlays but which yield the same dollar net benefits. For example, a project that costs $10,000 and yields benefits of $20,000 yields the same net benefits as one which costs $100,000 and yields benefits of $110,000. Hence, equations 6.7 and 6.8 are superior both to other B/C and SIR measures and to the individual project net benefits measure for ranking projects for investment priority.

TABLE 6.3 ECONOMIC EFFICIENCY COMPARISON OF TWO B/C FORMULATIONS: PUBLIC INVESTMENT DECISION

Project Alternatives (1)	PV Benefits (2)	PV Operating Costs (3)	Benefits Less Operating Costs (4)=(2)-(3)	PV Initial Investment Cost (5)	Total Net Benefits (B-C) (6)=(2)-(3)-(5)	Equation 6.1, B/C[a] Ratio (7)	Equation 6.1, B/C[a] Priority Ranking (8)	Equation 6.7, B/C[b] Ratio (9)	Equation 6.7, B/C[b] Priority Ranking (10)
A	$10,000	$6,000	$4,000	$1,000	$3,000	1.43	3	4.00	1
B	$ 2,000	$ -500	$2,500	$1,000	$1,500	4.00	1	2.50	3
C	$ 5,000	$1,500	$3,500	$1,000	$2,500	2.00	2	3.50	2

[a] Calculated according to equation 6.1; e.g., for project alternative A, $B/C = \frac{\$10,000}{\$1,000 + \$6,000} = 1.43$.

[b] Calculated according to equation 6.7; e.g., for project alternative A, $B/C = \frac{\$10,000 - \$6,000}{\$1,000} = 4.00$.

The hypothetical problem depicted in table 6.4 is one of choosing the most economically efficient energy conservation project for a building given a budget of $1,000. The budget allows only one of the three available projects (D, E, and F) to be undertaken. Project D, an automatic environmental control system requiring regular inspection and adjustment for satisfactory performance, saves the most in energy dollars, but gives rise to substantial maintenance cost. Project E is wall insulation requiring only an initial purchase and installation charge. Project F entails replacement of windows with a type that, unlike the old, does not require periodic recaulking and painting. SIR's calculated by equation 6.2 (col. 7) lead to the selection (col. 8) of Project F, which costs $1,000 (col. 5) and saves $3,000 in energy (col. 2) and another $600 in reduced maintenance (col. 3), for a total net savings of $2,600 (col. 6). Use of the SIR's calculated by equation 6.8 (col. 9) would result instead in the selection (col. 10) of Project E, costing $1,000 (col. 5) and saving $3,800 (col. 2) in energy, for a total net savings of $2,800 (col. 6). Hence, use of equation 6.8 to guide project selection would in this case revise net savings by $200.

In summary, equations 6.7 and 6.8 provide a consistent weighting of all future cash flows, provided investment cost (I) is an initial outlay, with no financing over time. In the case where I is funded out of equity, equations 6.7 and 6.8 will give highest ranking to cost-effective projects which have the largest return relative to the initial investment. Thus, these equations would be best for project selection when the investor desires to maximize the return on equity investment funds.

To the extent that investment costs are financed over time, equations 6.7 and 6.8 will give greater weight to future investment costs (because they are placed in the denominator) than to other future cash flows,[1] an effect which may or may not be desired by the investor. If a project is financed from a combination of equity and borrowed funds, for instance, the investor whose aim is to achieve the greatest return from equity funds may choose to formulate the B/C or SIR to place the downpayment in the denominator and to treat the present value of investment financing as an operating cost in the numerator. A ratio formulated in this manner would give greater priority to projects requiring less equity, other things being the same.

In calculating B/C's and SIR's, it is also important to take into account the nature of the problem to which they are applied. If used to compare projects that are not mutually exclusive, the B/C and SIR are calculated on project totals for the relevant data. But if used to compare alternative designs and/or sizes of a given project, i.e., mutually exclusive decisions, the B/C and SIR are calculated on incremental data corresponding to each step towards a larger project cost. These two approaches are demonstrated in the next section on applications.

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[1] This applies to projects for which the B/C or SIR is greater than one.

TABLE 6.4 ECONOMIC EFFICIENCY COMPARISON OF TWO SIR FORMULATIONS: PRIVATE SECTOR INVESTMENT DECISION

Project Alternatives (1)	PV Savings (2)	PV Maintenance Cost (3)	PV Net Future Cash Flow (4)=(2)-(3)	PV Initial Investment Cost (5)	Total Net PV (6)=(2)-(3)-(5)	Equation 6.2, SIR[a] Ratio (7)	Equation 6.2, SIR[a] Priority Ranking (8)	Equation 6.8, SIR[b] Ratio (9)	Equation 6.8, SIR[b] Priority Ranking (10)
D	$6,000	+$2,300	$3,700	$1,000	$2,700	1.82	3	3.70	2
E	$3,800	$ 0	$3,800	$1,000	$2,800	3.80	2	3.80	1
F	$3,000	-$ 600	$3,600	$1,000	$2,600	7.50	1	3.60	3

[a] Calculated according to equation 6.2; e.g., for project alternative D, $SIR = \frac{\$6,000}{\$1,000 + \$2,300} = 1.82$.

[b] Calculated according to equation 6.8; e.g., for project alternative D, $SIR = \frac{\$6,000 - \$2,300}{\$1,000} = 3.70$.

7. RECOMMENDED APPLICATIONS

The B/C or SIR technique can be used to indicate whether a given project is cost effective. If the B/C or SIR is less than one, the investor's minimum required rate of return, as reflected in the discount rate, is not being achieved and the project is not cost effective. If it is greater than one, the project exceeds the minimum required rate and is cost effective.

A second use of the B/C or SIR technique is to choose among non-mutually exclusive projects competing for a limited budget. For example, if a firm with extensive facilities to retrofit for energy conservation had only enough money to carry out one-third of the potentially cost-effective projects, net savings from the available budget could be maximized by undertaking projects in descending order of their SIR's until the budget is exhausted. (See appendix A and examples in tables 6.3 and 6.4 with accompanying text.)

During the initial budget period, all evaluated projects which best satisfy the cost-effectiveness criterion and which together exhaust the first year's budget would be selected. In subsequent budget periods all projects not previously selected should be reanalyzed if their SIR's are expected to have changed. They can then be ranked together with any new projects which have been identified.

The ranking and selection procedure over two one-year budget periods is illustrated graphically in figure 7.1. Projects are arranged in order of their priority ranking and a selection of projects is made in accordance with a limited budget. There are six candidate projects depicted in the first year as meeting the minimum cost-effectiveness criterion by having a B/C or SIR of one or greater. However, the budget in that year only allows for the first three to be funded. In the second year the budget allows for the remaining three projects. A fourth new candidate project in that year is omitted because of the budget constraint.

In using the B/C or SIR for capital rationing, it is important that the ratios for all projects being compared reflect the same opportunity cost of capital as incorporated in the discount rate. If the B/C or SIR values are calculated with different discount rates for different projects, the resulting rankings will not necessarily lead to the maximization of net benefits. Furthermore, it is important that the opportunity cost of capital be used as the basis for the discount rate.[1]

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[1] The opportunity cost of capital is the rate of return available on the next best available investment.

Figure 7.1 Allocating the Budget Among Alternative Projects Ranked by B/C or SIR

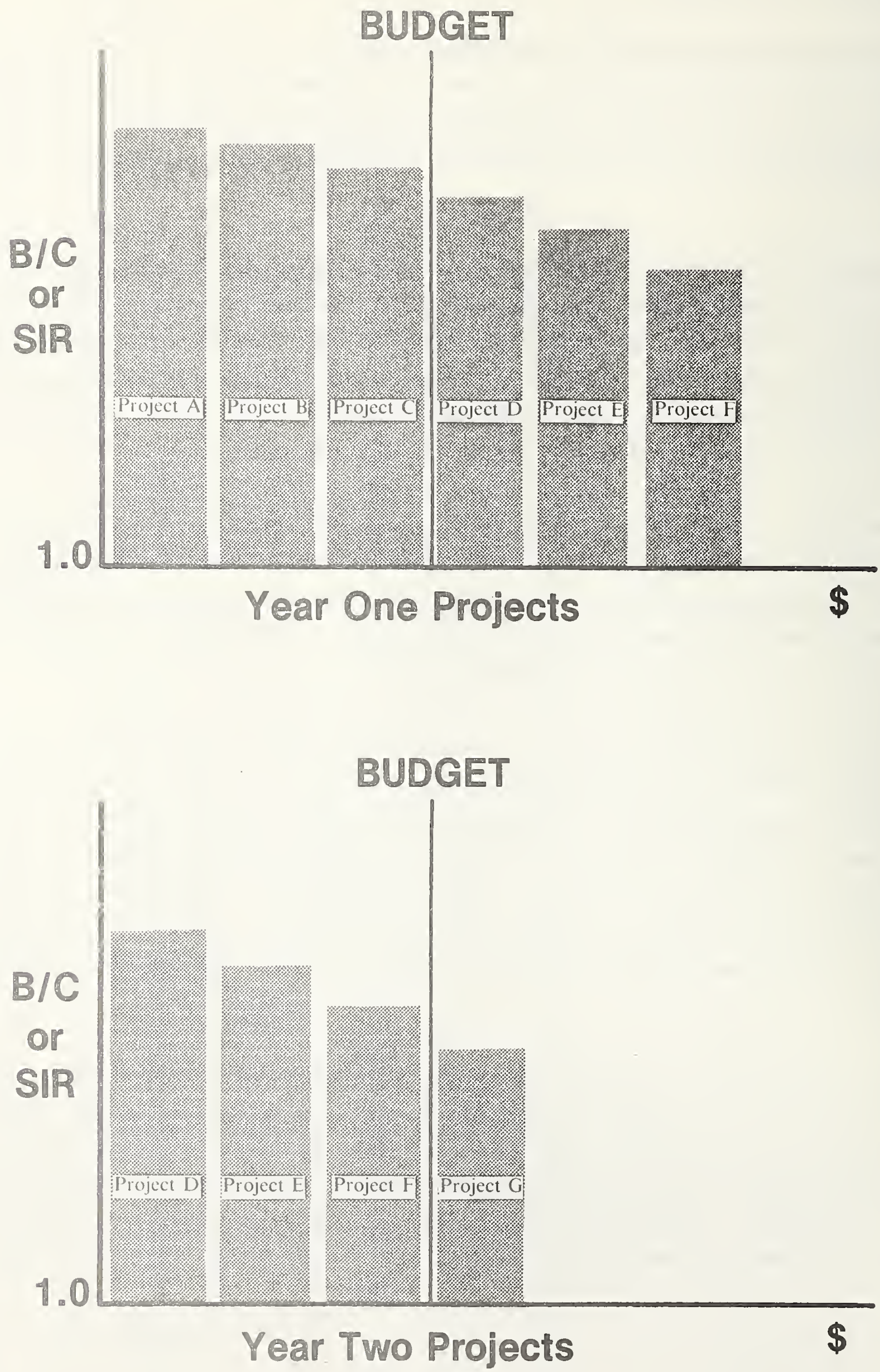

Table 7.1 illustrates the sensitivity of the B/C and project net benefits to variations in the discount rate. For example, the B/C values in col. (7) show that project 1 receives first priority, project 3, second, and project 2, third, when calculated at a 6 percent discount rate. If, on the other hand, a higher opportunity cost indicated a 25 percent discount rate as shown in col. (8), the second project would receive first priority, the first project second priority, and the third project last priority. Using the incorrect discount rate may lead to fewer net benefits per investment dollar, as would be the case in table 7.1 if, for example, projects were chosen on the basis of a 6 percent discount rate when the correct rate was 25 percent.

A third application of the B/C or SIR technique is to determine which project size or design is most efficient (i.e., which maximizes net benefits or net savings). If there is no budget limitation for a given project, the most efficient size or design occurs when the ratio of incremental benefits or savings to incremental cost is equal to one for the last unit of investment (i.e., where marginal benefits equal marginal costs). With a budget constraint, however, it pays to restrict project size or design to that investment for which the ratio of incremental benefits or savings to incremental costs for the last unit of investment in the project is just equal to the incremental ratio on the next best available investment. In other words, an incremental B/C or SIR greater than one might be adopted as a "cutoff ratio" beyond which it would not pay to increase size or alter the design. If B/C analysis is to be used for project design or sizing, it must be on an incremental basis.

Table 7.2, table 7.3, and figure 7.2 together illustrate how project size can be selected on the basis of incremental B/C analysis. Table 7.2 presents five size alternatives (zero and A through D) and their corresponding benefits and costs. Alternative C results in the maximum net benefits and, hence, would be the economically efficient choice if there are no budget constraints.

Table 7.3 shows the B/C's for all possible size changes for the alternatives described in table 7.2. Table 7.3 is read by row from left to right. The top row gives, in effect, the B/C's on total investment. Although size A has the highest B/C, it is not the size that is shown in table 7.2 to give the highest net benefits. (Table 7.2 shows that net benefits from project size C are $55,000 more than net benefits from project A.)

Subsequent rows of table 7.3 give the incremental B/C's calculated on the differences between project sizes other than zero. For example, the incremental B/C associated with expanding project size from A to B is 3.0; from A to C, 2.2;[1] from A to D, 1.9; and from B to C, 1.3.

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[1] The calculation of B/C from A to C, for example, is $\frac{600,000 - 500,000}{145,000 - 100,000} = 2.2$.

TABLE 7.1 SENSITIVITY OF THE B/C AND NET BENEFITS TO VARIATIONS IN THE DISCOUNT RATE

Competing, Independent Projects (1)	Investment Required ($) (2)	Annual Project Benefits[a] ($) (3)	Project Life (Years) (4)	Project Net Benefits ($) 6% Discount Rate (5)	Project Net Benefits ($) 25% Discount Rate (6)	Project B/C's 6% Discount Rate (7)	Project B/C's 25% Discount Rate (8)
1	10,000	10,000	10	63,500	25,710	7.36	3.57
2	10,000	15,000	5	53,180	30,355	6.32	4.03
3	10,000	5,000	30	58,825	9,975	6.89	2.00

a For simplicity, cash flows are assumed to comprise only investment costs and benefits.

TABLE 7.2 PROJECT DATA

Project Size Alternatives	Total Investment Required ($)	Project Life (Years)	Total Benefits ($)	Net Benefits ($)
0	0	0	0	0
A	100,000	20	500,000	400,000
B	125,000	20	575,000	450,000
C	145,000	20	600,000	455,000
D	155,000	20	605,000	450,000

TABLE 7.3 B/C's FOR PROJECT SIZE CHANGES[a]

From Size \ To Size	0	A	B	C	D
0	0	5.0	4.6	4.1	3.9
A			3.0	2.2	1.9
B				1.3	1.0
C					0.5

[a] Based on data presented in table 7.2.

Figure 7.2 Network Diagram Using Incremental B/C Analysis for Project Sizing

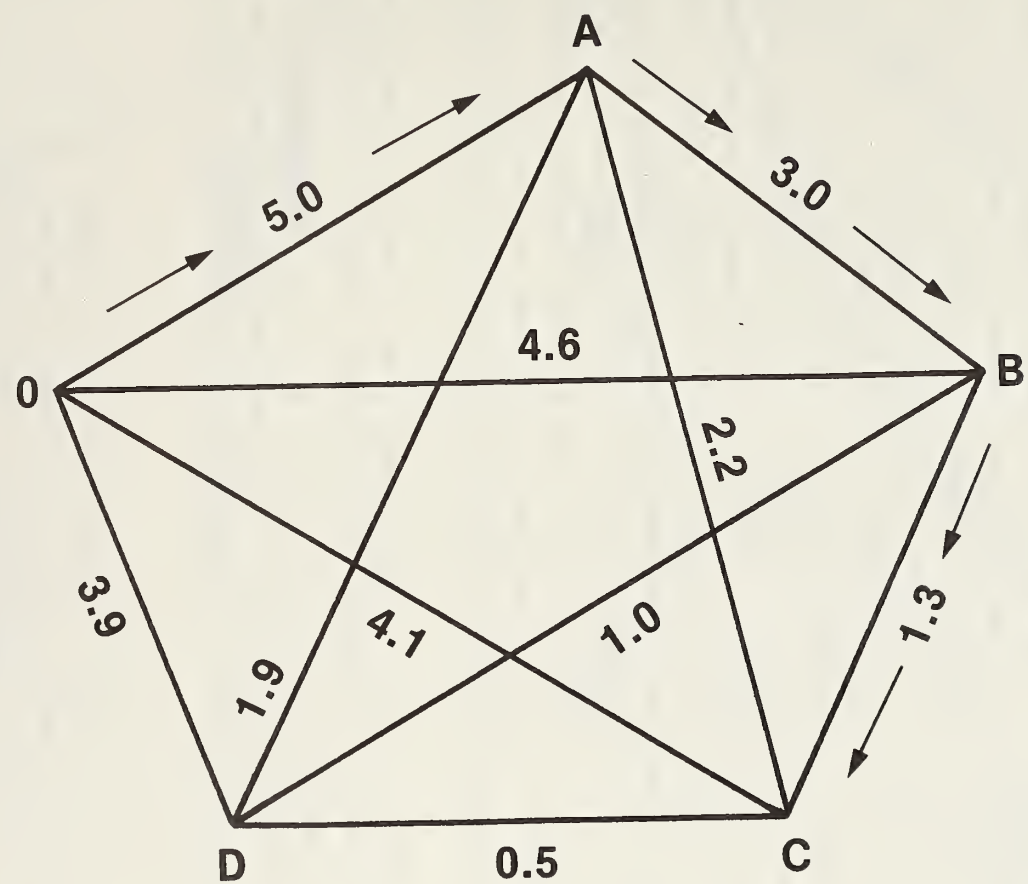
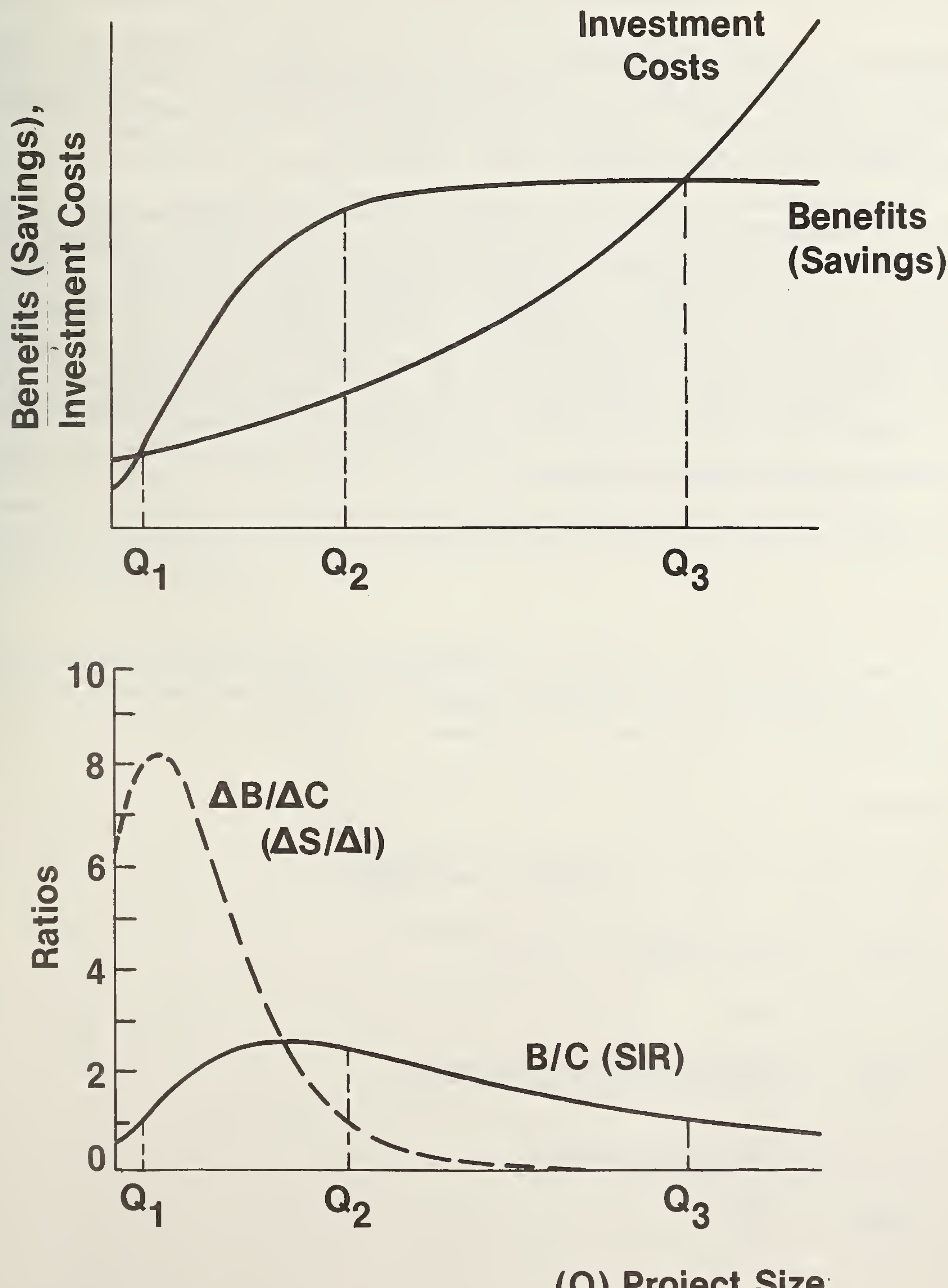


Figure 7.2 shows in a network diagram the matrix of B/C's for all potential sizing options. Each line in the network connects either 0 and a lettered point or two lettered points, and depicts a potential project sizing decision. The number appearing by each connecting line is the B/C calculated on the benefits and costs of the represented decision. One example is the line connecting 0 and D. It indicates that one could potentially choose the largest project, size D, at the outset, with a B/C on total investment of 3.9. A second example is the line connecting B and D which shows that project size B could be expanded to size D, attaining a B/C on the incremental investment of 1.0. In both cases the B/C's are one or greater, indicating project cost effectiveness. However, a more detailed inspection of the increments comprising project D shows that project D is not the most cost-effective size. That is, size D is comprised of increment 0 to A (B/C = 5.0), plus increment A to B (B/C = 3.0), plus increment B to C (B/C = 1.3), plus increment C to D (B/C = 0.5). Even with no budget constraint, the last increment to project size D (i.e., C to D) is not cost effective as indicated by the incremental B/C of 0.5. Thus, to find the most efficient project size, one increases the size by each separable increment until the incremental B/C equals or just exceeds the cutoff B/C. A larger size would reduce total net benefits from the project. For example, if the cutoff B/C were 1.8, increments A and B would be efficient, but anything beyond would not. If there were no budget constraint, or if the cutoff B/C were less than 1.3, then increment C would also be desirable, because it brings more benefits than it costs. The diagram shows by means of arrows the path along which project size would be expanded to C. This is consistent with what was found in table 7.2 where C was found to be the size that maximized net benefits when there is no budget constraint.

The determination of the efficient project size is further illustrated by figure 7.3. Any size (Q) between Q_1 and Q_3 would be economically efficient in the general sense of having benefits or savings in excess of costs. That is, the benefits (savings) function lies above the cost function as shown on the upper graph, or, expressing the same concept in another way, the B/C (SIR) is greater-than-or-equal-to one over this size range, as shown on the bottom graph.

The most efficient size of a project would be Q_2 in figure 7.3. This is the size for which the difference in benefits (savings) and costs is greatest, i.e., where net benefits or net savings are maximized, as shown in the top graph. It is also the size for which the incremental B/C (SIR), as measured by $\Delta B/\Delta C$ ($\Delta S/\Delta I$) in the lower graph, is equal to one. Note that the B/C (SIR) based on total benefits (savings) and costs does not indicate the most

Figure 7.3 Efficient Project Sizes



efficient size, either at the point that it is equal to one or at its maximum point. Rather, it is the incremental ratio that indicates the most efficient size.[1]

The most efficient size would be smaller than Q_2 if the budget were limited and if other projects with a higher incremental ratio than one were available. In the case of a cutoff ratio of 2.3, for example, a project size between Q_1 and Q_2 would be selected where the incremental ratio is just equivalent to the cutoff ratio.

Where there are several non-mutually exclusive projects with positive net benefits and there is an insufficient budget to fund all of them, the theoretically correct approach would be to size each project such that the incremental B/C ratios would be equal for all projects and equal to the ratio available on the last increment of the next best investment (i.e., equal to the opportunity cost). Then projects would be selected on the basis of descending B/C's or SIR's computed on the total project costs and benefits (savings) until the budget is exhausted. However, due to the difficulty of simultaneously equating the incremental ratios on all projects, a second best approach often used is to size each

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[1] It can be proved that if B/C is at its maximum, then $B'/C' = B/C$; i.e., the locus of points defining the ratio of marginal benefits to marginal costs intersects the ratio of total benefits to total costs at its maximum.

Given $B,C > 0$, $B',C' > 0$, $B'' < 0$, and $C'' > 0$,

Maximizing B/C implies that $\frac{d(B/C)}{dQ} = 0$ and $\frac{d^2(B/C)}{dQ^2} < 0$.

$\frac{d(B/C)}{dQ} = 0$ implies $\frac{CB'-BC'}{C^2} = 0$ implies $CB'-BC' = 0$.

Thus $B'/C' = B/C$.

$$\frac{d^2(B/C)}{dQ^2} = \frac{C^2\,(CB''+C'B'-B'C'-B'C'') - (CB'-BC')C^2}{C^4},$$

which upon simplification reduces to

$$\frac{d^2(B/C)}{dQ^2} = \frac{CB''-BC''}{C^2}.$$

Since C and B are greater than zero and by assumption $C''>0$ and $B''<0$, then $\frac{d^2(B/C)}{dQ^2} < 0$.

project so that the incremental ratio is equal to one. Projects are then selected as before in descending order of B/C's or SIR's until the budget is exhausted.

A further limitation on the application of the SIR technique should be noted. In evaluating candidate projects for a particular building or facility, the problem of interdependency among projects may arise; that is, undertaking one project may affect the relative life-cycle costs and savings of remaining projects. Thus the value of adding an automatic environmental control system will be different depending on the level of insulation in the building envelope and vice versa. Undertaking one will tend to diminish the value of the other. Often a practical approach to this problem is to evaluate each of the candidate projects independently of one another, select the one with the highest B/C or SIR, and then adjust the B/C or SIR of any remaining projects that are expected to be substantially altered by the first, higher priority selection. The selection process can then be continued, with necessary adjustments to remaining projects being made as each project is chosen.

Appendix A illustrates the application of the SIR technique to a sample problem in energy conservation involving both decisions in sizing and in the selection of an efficient combination of conservation options. Appendix B follows with some selected references on the B/C and SIR techniques.

APPENDIX A

SIR EVALUATIONS OF ENERGY CONSERVATION INVESTMENTS[1]

A home improvements firm has been contracted to plan and install an energy conservation package for the owner/occupant of the house described below. Candidate retrofit projects have been proposed, and the owners want to know what combination of those projects would maximize net savings to them for their conservation budget of $1,500. For each of the candidate projects an SIR is computed along with the corresponding net savings of that project.

The house has been previously 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 already 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. For purposes of illustration, the efficiency of the system is assumed to be 100 percent.

The annual space heating load is 83×10^6 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 22×10^6 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

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[1] This problem is adapted from problem 7.14 in Marshall and Ruegg, Energy Conservation in Buildings: An Economics Guidebook, pp. 100-110.

budget. Their best alternative return on the $1,500 is an 8 percent market rate from tax-exempt municipal bonds.

The following options are being considered for retrofit to the house:[1]

(A) Addition of a solar domestic water heater. The system that has been recommended is 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 annual 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 over the cost of the R-19 addition, and is expected to reduce energy consumption by 5 percent of the heating costs at R-19.[2]

(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.

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[1] The options selected are purely for illustrative purposes and are not intended as an endorsement or recommendation of these particular investments.

[2] 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.

(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.[1]

(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 it is assumed that there are no available grants or tax credits and that property taxes are not expected to be affected by the retrofit investments.

Solution

Compute the present value (PV) of costs, savings, 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.[2] 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:

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[1] 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.

[2] Equation 6.8 is used to compute the SIR's.

(A) Addition of a Solar Domestic Water Heater

PV Cost = \$1,500

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

where UPW* is taken from a table of discount factors.

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

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

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

= \$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

(C) <u>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) <u>Addition of Attic Insulation, R-19 to R-30</u>

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 Savings = ($22,655.06 [PV Space Heating] − $2,718.61 [After R-19]) x 0.05 [% Reduction] = $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 Savings = ($9,711.48 [PV Space Heating] − $1,165.38 [After R-19]) x 0.05 [% Reduction] = $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 A.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 A.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 A.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 A.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 A.5 lists that set of projects.

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 heating costs.

TABLE A.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

Given that project costs occur in varied amounts, depending on the project, the full $1,500 is not allocated, and $25 remains unallocated. In this case the net savings from undertaking these projects are greater than from any other combination of projects which <u>would</u> exhaust the total budget. However, under some circumstances, selecting a lower ranked project that exhausts the budget might increase total net benefits.

In summary, the package of energy conservation projects which in this illustrative example 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.

APPENDIX B

SELECTED B/C AND SIR REFERENCES

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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

This report describes how to calculate a benefit-cost ratio (B/C) and a savings-to-investment ratio (SIR) and how to use them in selecting building designs and building systems that will be cost effective in the long run. The B/C relates positive benefits, such as revenues, to project costs in the form of a ratio. The SIR, a variation of the B/C, relates project savings (i.e., cost reductions) to project costs in a ratio. It is used when there are few if any positive cash flows from a project. The B/C and SIR can be used to help answer such questions as: "Is a project cost effective?" "Which size and/or design of a project is most cost effective?" "What priorities should be given individual projects competing for a limited budget?" The report addresses different formulations of the ratios and their implications for selecting cost-effective projects.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

benefit-cost analysis; building economics; cost effective; economic analysis; energy conservation; investment analysis; life-cycle cost; recommended practice; savings-to-investment ratio

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