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Benefits and Costs of Research: Two Case Studies in Building Technology

Robert E. Chapman and Sieglinde K. Fuller

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Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

U.S. DEPARTMENT OF COMMERCE
Michael Kantor, Secretary
Technology Administration
Mary L. Good, Under Secretary for Technology
National Institute of Standards and Technology
Arati Prabhakar, Director

Abstract

The National Institute of Standards and Technology (NIST) is improving its resource allocation process by doing "microstudies" of its research impacts on society. This report is the outgrowth of a series of microstudies prepared by NIST's Building and Fire Research Laboratory (BFRL).

This report has four major purposes. First, it examines five evaluation methods for measuring the economic impacts of research investments. Second, it establishes a framework for identifying, classifying, quantifying, and analyzing the benefits and costs of research investments. Third, it presents a generic format for summarizing the economic impacts of research investments. Fourth, it illustrates—by way of two case studies—how the framework, evaluation methods, and generic format would be applied in practice.

The first case study provides estimates of the economic impacts from past BFRL research leading to the introduction of the ASHRAE 90-75 standard for residential energy conservation. The energy costs of the ASHRAE 90-75 standard are compared to those of pre-1973 oil embargo standards. More than $900 million (in 1975 dollars) of the energy savings from ASHRAE 90-75 modifications in single-family houses were directly attributable to the BFRL activities that promoted the development of ASHRAE 90-75.

The second case study provides estimates of the net dollar savings from a past BFRL research effort leading to the development of an improved asphalt shingle for sloped roofing. BFRL's contribution resulted in a faster adoption of the longer-lasting 235 shingle, which significantly reduced roofing costs to building owners.

Keywords

benefit-cost analysis; building economics; building materials; buildings; construction; economic analysis; energy conservation; evaluation methods; research impacts

Preface

This study was conducted by the Office of Applied Economics in the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST). The goal of this study was to demonstrate how standardized evaluation methods can be used to evaluate the benefits and costs of research. In addition, the study is designed to help BFRL estimate the economic impacts resulting from its research and to estimate the return of BFRL's research investment dollars. The intended audience for this report is the National Institute of Standards and Technology as well as other government and private research groups that are concerned with determining efficient allocations of their research budgets.

The measurement of economic impacts of research is a major interest of BFRL and of NIST. Managers need to know the impact of their research programs in order to achieve the maximum social benefits from their limited budgets. Standardized methods for measuring economic impacts are essential to support BFRL's effort to evaluate the cost effectiveness of completed research projects. As additional experience is gained with the application of these standardized methods, their use will enable BFRL to select the "best" among competing research programs, to evaluate how cost effective are existing research programs, and to defend or terminate programs on the basis of their economic impact. This need for measurement methods exists across programs in BFRL, in NIST, and in other research laboratories.

Acknowledgments

The authors wish to thank all those who contributed so many excellent ideas and suggestions which we have attempted to incorporate into this report. Special appreciation is extended to Dr. Harold E. Marshall and Dr. Stephen F. Weber of the Office of Applied Economics at NIST's Building and Fire Research Laboratory (BFRL) for the thoroughness of their reviews and for their many insights and to Ms. Laurene Linsenmayer for her assistance in preparing the manuscript for review and publication. Special appreciation is also extended to Mr. Stephen R. Petersen of BFRL both for his assistance in calculating several key evaluation measures and for his insights on setting the discount rate for government-sponsored research projects. Thanks are due to Dr. Mark Ehlen of BFRL for sharing his insights on classifying benefits and costs of building research efforts, to Mr. James L. Heldenbrand of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) for historical information concerning the development of the ASHRAE Standard 90-75, and to Dr. Walter J. Rossiter of BFRL and Mr. Peter Kelley of the American Roofing Manufacturers' Association for information on the roofing industry and the use of 235 shingles. The report has also benefitted from the reviews and technical comments provided by Dr. Christoph Witzgall of NIST's Computing and Applied Mathematics Laboratory and by Mr. Noel J. Raufaste of BFRL.

Contents

Contents (continued)

Page

Contents (continued)

LIST OF TABLES

Contents (continued)

Page

LIST OF TABLES (continued)

LIST OF FIGURES

Contents (continued)

Page

LIST OF EXHIBITS

Executive Summary

The National Institute of Standards and Technology (NIST), a scientific research agency of the U.S. Department of Commerce's Technology Administration, is improving its resource allocation process by doing "microstudies" of its research impacts on society. This report is the first in a series of impact studies prepared by NIST's Building and Fire Research Laboratory (BFRL). It is intended to be a resource document for conducting research on the assessment of economic impacts and a guide for practitioners. Consequently, it provides a level of detail which enables others to follow the flow of the analysis, gain insights useful for their applications, and reproduce the results shown in the two case studies. While the companion report[a] and future reports provide insights on the practice of evaluating the economic impacts of research investments, they only summarize the methodological issues covered in detail in this report.

The report has seven chapters. Chapter 1 explains the purpose, scope, and general approach of the study. The methodology and framework for measuring economic impacts are established in chapter 2. Chapter 3 provides a description of five evaluation methods for measuring the economic impacts of research investments; each method employs a standard practice which has been adopted by the American Society for Testing and Materials (ASTM).[b] Chapter 4 outlines a generic format for presenting and analyzing the results of an economic impact study. Two case studies of building technologies are developed in chapters 5 and 6. These case studies illustrate how to apply in practice the framework, evaluation methods, and generic format described in chapters 2 through 4 to evaluate, compare, and summarize the economic impacts of research investments. Chapter 7 concludes the report with a summary and suggestions for further research.

Chapter 2 establishes the basic methodology and framework for measuring the economic impacts of research investments. The chapter begins with an overview of benefit-cost analysis. Four key concepts are then introduced and outlined. First, we discuss the need to identify and classify benefits and costs. Second, we provide a mathematical formulation for mapping benefits and costs into each of the evaluation methods described in chapter 3. Next, we discuss a series of technical considerations such as the need to discount benefits and costs to an equivalent time basis for purpose of comparison, the challenges of estimating benefits and costs, and the crucial role of data in developing such estimates. Finally, we discuss how to use sensitivity analysis to evaluate the effects of uncertainty.

Chapter 3 presents the five evaluation methods that are most appropriate for measuring the economic impacts of research investments: (1) Present Value of Net Benefits (PVNB); (2) Present Value of Net Savings (PVNS); (3) Benefit-to-Cost Ratio (BCR); (4) Savings-to-Investment Ratio (SIR); and (5) Adjusted Internal Rate of Return (AIRR). Each evaluation method employs an ASTM standard practice and is derived from the mathematical formulation given in chapter 2. Since investment decisions differ in their objectives, chapter 3 concludes with an analysis of when, and under what circumstances, it is appropriate to use each evaluation method. The PVNB (PVNS) measures the overall magnitude of the benefits (cost savings) net of the costs of undertaking the research. The BCR (SIR) measures the benefits

[a] The second report in the series focuses on a fire technology application—the Fire Safety Evaluation System for health care facilities. See Chapman, Robert E., and Stephen F. Weber. 1996. *Benefits and Costs of Research: A Case Study of the Fire Safety Evaluation System.* NISTIR 5863. Gaithersburg, MD: National Institute of Standards and Technology.

[b] American Society for Testing and Materials (ASTM). 1994. *ASTM Standards on Building Economics.* Philadelphia, PA: American Society for Testing and Materials.

(cost savings) per unit cost of the research. The AIRR is the annual percentage yield from a project over the study period, taking into account the reinvestment of interim receipts. All five methods apply to Accept/Reject decisions. Both PVNB and PVNS are appropriate for Design/Size decisions (selecting one among mutually exclusive alternatives). The BCR, SIR, and AIRR are appropriate for ranking alternatives under a budget constraint.

Chapter 4 outlines a generic format for presenting and analyzing the results of an economic impact study. The generic format is built upon three factors: (1) the significance of the research effort; (2) the analysis strategy; and (3) the calculation of key benefit and cost measures. The generic format provides a vehicle for clearly and concisely summarizing the salient results of an economic impact study to senior research managers (e.g., laboratory directors). A specific format, tailored to BFRL, is also included (see, exhibit 4-1); it provides the basis for summaries of the two case study applications given in chapters 5 and 6.

The first case study, described in chapter 5, provides estimates of the economic impacts from past BFRL research leading to the introduction of a new standard for residential energy conservation. This research project was begun in 1973 in response to a growing need to produce a set of design criteria which could be used as the basis for a consensus standard on energy conservation in new buildings. Among the private sector leaders in this area were the National Conference of States on Building Codes and Standards (NCSBCS) and the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE). NCSBCS requested BFRL to take the lead in developing the technical basis for the consensus standard. In early 1974, BFRL issued a report[c] that became the technical basis for ASHRAE Standard 90-75. ASHRAE adopted the standard in 1975. The analysis presented in chapter 5 proceeds in two stages. First, estimated energy cost savings, information on actual adoption rates of ASHRAE 90-75 by states, and the resulting number of new single-family residences covered by the standard are used to measure the economic impacts of ASHRAE 90-75. Second, the value of BFRL's contribution is measured. To derive an estimate of energy cost savings, the energy costs of "prototypical" single-family residences covered by ASHRAE 90-75 are compared to those of pre-1973 oil embargo energy standards. The case study estimates the energy cost savings from ASHRAE 90-75 modifications in single-family residences constructed over the period from 1975 through 1984. The issuance of ASHRAE 90-75 had a significant impact on energy cost savings in buildings throughout the United States; for single-family residences, the total present value of net savings amounted to nearly $1.5 billion in 1975 dollars. BFRL's contribution resulted in a more timely adoption of ASHRAE 90-75. If BFRL had not been involved, ASHRAE estimates that it would have taken an additional four years to develop a similar consensus standard which all parties could support. The value of BFRL's contribution is based on the elimination of the potential four-year delay. Information presented in chapter 5, and summarized in exhibit 5-1, documents that more than $900 million of the $1.5 billion overall present value of net savings were directly attributable to the BFRL activities that promoted the development and timely adoption of ASHRAE 90-75.

The second case study, described in chapter 6, provides estimates of the net dollar savings from a past research effort in the development of an improved asphalt shingle for sloped roofing. This project was begun in 1958 at the request of the Tri-Services Committee of the Department of Defense to address a problem of frequent roof replacements caused by a type of shingle failure called "clawing." BFRL developed specifications which were adopted by the roofing industry in 1962. Almost immediately

[c]National Bureau of Standards. 1974 (Revised 1976). *Design and Evaluation Criteria for Energy Conservation in New Buildings.* NBSIR 74-452. Gaithersburg, MD: National Bureau of Standards.

thereafter, the 235 shingle was introduced to replace the 210 shingle.[d] The costs of the improved shingle are compared against the costs of the shingle it replaced. Net savings are computed for the actual quantity of the improved shingle that was installed during the period from 1962 to 1974. The adoption of the longer-lasting 235 shingles to replace the failing 210 shingles had a significant impact on roofing costs, resulting in a present value of net savings to consumers of nearly $4 billion in 1974 dollars over the 13-year period from 1962 to 1974. Roofing experts estimate that the availability of the 235 shingle would have been delayed from 2 to 5 years had it not been for BFRL's participation in, and coordination of, the development and promotion of the 235 shingle. Estimates presented in chapter 6 measure the value of BFRL's contribution based on a three-year delay. These estimates, recorded in exhibit 6-1, show that BFRL's activities were directly responsible for more than $1.7 billion of the overall present value of net savings to consumers over the 13-year period between 1962 and 1974.

Chapter 6 discusses additional areas of research that might be of value to government agencies and other institutions that are concerned with an efficient allocation of their research budgets. These areas of research are concerned with: (1) the development of a standard classification of research benefits and costs; (2) factors affecting the diffusion of new technologies; (3) conducting *ex ante* evaluations with scheduled follow-ups; and (4) evaluations based on multiattribute decision analysis.

[d]The designation for the type of shingle—210 and 235—reflects the weight per sales square. A sales square—the customary unit by which shingles are sold—is the quantity of shingles needed to cover 100 square feet of roofing surface (e.g., 210 pounds or 235 pounds).

1. Introduction

1.1 Background

The pressures of competing in the global marketplace are affecting nearly every U.S. business. Now more than ever, U.S. businesses are finding that they must continuously improve their products and services if they are to survive and prosper. Research, with its potential for incremental and breakthrough improvement, is of central importance to most businesses' continuous improvement efforts. It is now widely recognized that a key component of the competitiveness problem lies in the "inability of American companies (or, more accurately, the U.S.-based portions of what are fast becoming global technology firms) to transform discoveries quickly into high-quality products and into processes for designing, manufacturing, marketing, and distributing such products."[1]

Increasingly, the winners in the competitiveness race are those businesses that most rapidly make use of the fruits of research (e.g., new data, insights, inventions, prototypes). Efforts underway at the National Institute of Standards and Technology (NIST) and elsewhere in the U.S. focus on speeding up the commercial application of basic and applied research results. *The purpose of this report and its companion[2] is to respond to the following question: "How do we measure the results of our investments in technology development and application?"[3]* This report establishes the theoretical and technical considerations needed to measure the economic impacts of research investments. The companion report draws on these considerations and illustrates them via a case study approach. The goal of this report is to help managers at NIST, at other federal laboratories, and elsewhere, to better understand the economic impacts of their research in order to achieve the maximum social benefits from their limited budgets.

There are several reasons for measuring the economic impacts of a federal laboratory's research program. First, economic impact studies are a management tool; they help set priorities and point to new research opportunities. Second, as federal laboratories become more customer oriented, by revealing the "voice of the customer," such studies will strengthen the ties to industry and identify opportunities for leveraging federal research investments. Finally, changing requirements, such as the Government Performance and Results Act, will affect how federal research funds are allocated. Increasingly, federal agencies and laboratories which can not demonstrate that their research efforts complement those of industry and that they are having a positive impact on society will be at a disadvantage when competing for federal research funds.

NIST's research laboratories serve all sectors of U.S. industry through focused research programs. Each laboratory has cultivated strong working relationships with industrial, trade and professional organizations in its areas of technology concentration. The program of NIST's Building and Fire Research Laboratory (BFRL) is guided by a prioritized research agenda developed by experts from the building and fire communities. Its performance prediction and measurement technologies enhance the competitiveness of

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[1]Reich, Robert W. 1989. "The Quiet Path to Technological Preeminence." *Scientific American* (October): pp. 41-7.

[2]Chapman, Robert E., and Stephen F. Weber. 1996. *Benefits and Costs of Research: A Case Study of the Fire Safety Evaluation System*. NISTIR 5863. Gaithersburg, MD: National Institute of Standards and Technology (In Press).

[3]Good, Mary, and Arati Prabhakar. 1994. "Foreword." In Mark Bello and Michael Baum, *Setting Priorities and Measuring Results at the National Institute of Standards and Technology*. Gaithersburg, MD: National Institute of Standards and Technology.

U.S. industry and public safety. Specifically, BFRL is dedicated to improving the life-cycle quality of constructed facilities. BFRL studies structural, mechanical, and environmental engineering, fire science and fire safety engineering, building materials, and computer integrated construction practices.

To further strengthen its ties to industry, BFRL is actively participating in the Subcommittee on Construction and Building of the National Science and Technology Council (NSTC). The NSTC, a cabinet-level group charged with setting federal technology policy, coordinates research strategies across a broad cross-section of public and private interests. The Subcommittee on Construction and Building coordinates and defines priorities for federal research, development, and deployment related to the industries that produce, operate, and maintain constructed facilities, including, buildings and infrastructure.[4]

BFRL has long recognized the value of measuring the impacts of its research program. Previous studies have shown that even modest research efforts within BFRL are capable of producing significant impacts.[5] One reason for such outcomes is the unique mix of research facilities and skills possessed by BFRL and its staff. Through many years of active collaboration with its various user communities, BFRL's research findings are highly regarded when new construction, building, and disaster mitigation technologies are considered for introduction into the U.S. market.

1.2 Purpose

This report is the first in a series of impact studies prepared by BFRL. It is intended to be a resource document for conducting research on the assessment of economic impacts and a guide for practitioners. Consequently, it provides a level of detail which will enable others to follow the flow of the analysis, gain insights useful for their applications, and reproduce the results shown in the two case studies. While the companion document[6] and future reports in the series provide insights on the practice of evaluating the economic impacts of research investments, they only summarize the methodological issues covered in detail in this report.

This report has four major purposes. First, it provides research managers (e.g., BFRL and NIST) with an examination of five evaluation methods for measuring the economic impacts of research investments. This review of methods for evaluating the economic impacts of research projects is in an effort to promote more efficient allocations of limited research funds. The measurement of economic impacts based on the standardized methods described in this report will enable BFRL and NIST to give better service to the building and fire communities and to the nation's economy in general.

The second purpose of this report is to establish a conceptual and mathematical framework for identifying, classifying, quantifying, and analyzing the benefits and costs of research investments. This framework and its associated data requirements constitute a four stage process for estimating the economic impacts *ex ante*

[4]Seven goals to enhance the competitiveness of the U.S. construction industry are explicit in the mission of the Subcommittee. For a detailed description of these goals and how the Subcommittee on Construction and Building will approach them see Wright, Richard N., Arthur H. Rosenfeld, and Andrew J. Fowell. 1995. *Construction and Building: Federal Research and Development in Support of the U.S. Construction Industry.* Washington, DC: National Science and Technology Council.

[5]Marshall, Harold E., and Rosalie T. Ruegg. 1979. *Efficient Allocation of Research Funds: Economic Evaluation Methods with Case Studies in Building Technology.* NBS Special Publication 558. Gaithersburg, MD: National Bureau of Standards.

[6]Chapman and Weber, *A Case Study of the Fire Safety Evaluation System.*

of new standards and/or technologies and *ex post* of past research efforts. This framework also serves as a foundation from which the five standardized methods may be derived and critically analyzed.

The third purpose is to present a generic format for summarizing the economic impacts of research investments.

The fourth purpose of this report is to illustrate how the framework, standardized methods, and generic format would be applied in practice. This purpose is accomplished by way of two case studies of building technologies. Both case studies are *ex post* in that they are based on past research efforts. The selection of the two case studies included in this report was influenced by the availability of data and other factual information. Although our stated goal was to illustrate how the framework, standardized methods, and generic format would be applied in practice, a broader purpose was achieved. Because both case studies were *ex post* and detailed information was available on the adoption and use of the results of BFRL's research efforts, the presentation of the material in both case studies—assumptions, data, analysis, and results—may be used as a tutorial on how to assess the economic impacts of a research project.

1.3 Scope and Approach

This report takes a long-run view of research planning and evaluation. The focus is on specific benefits and costs of research investments, with little attention being given to institutional considerations and other constraining factors. Examples of such constraining factors which research managers are likely to find important are the compatibility of research projects with the organization's mission and the ability to perform those projects within budget constraints.

Little attention is given in this report to the step-by-step process by which research in BFRL (or other laboratories) makes its way (i.e., diffuses) as a new technology through codes, standards, or other processes to the ultimate user. Modeling the diffusion process for a new technology is a major research task in itself.

The report has six chapters in addition to the Introduction. Chapter 2 establishes the basic methodology for measuring the economic impacts of a research project, of a research program, or of a new technology. Because the material in chapter 2 emphasizes an approach that is applicable to economic impact studies in general, it is written in a more abstract form than the chapters which contain the case studies. The chapter begins with an overview of benefit-cost analysis. Four key concepts are then introduced and outlined. First, the need to identify and classify benefits and costs is discussed. Second, a mathematical formulation is given. The mathematical formulation provides the vehicle for mapping benefits and costs into each of the standardized methods described in chapter 3. Next, a series of technical considerations are discussed. These considerations include such important topics as the need to discount benefits and costs to an equivalent time basis for purpose of comparison, the challenges of estimating benefits and costs, and the crucial role of data in developing such estimates. Finally, how the use of sensitivity analysis permits the effects of uncertainty to be evaluated is discussed.

Chapter 3 provides a description of five standardized evaluation methods for measuring the economic impacts of research investments. Each standardized method is derived from the mathematical formulation given in chapter 2. Since investment decisions often differ in their objectives, chapter 3 concludes with an analysis of when, and under what circumstances, it is appropriate to use each standardized method.

Chapter 4 outlines a generic format for presenting and analyzing the results of an economic impact study. The generic format is built upon three factors: (1) the significance of the research effort; (2) the analysis strategy; and (3) the calculation of key benefit and cost measures. The generic format provides a vehicle for clearly and concisely summarizing the salient results of an economic impact study to senior research managers (e.g., laboratory directors). A specific format, tailored to BFRL, is also included; it provides the basis for summaries of the two case study applications given in chapters 5 and 6.

Two case studies of building technologies are developed in chapters 5 and 6. These case studies illustrate how to apply in practice the framework, standardized methods, and generic format described in chapters 2 through 4 to evaluate and compare the economic impacts of research investments. The first case study on residential energy conservation relates well to the four major purposes of this report. Thus it is presented in detail. The other case study is presented in a summary fashion since it is based on material presented in an earlier report.[7] It includes sufficient detail to understand the basis for the economic impact analysis and to reproduce the results.

The case studies are designed to be self contained. Consequently, readers already familiar with the key concepts laid out in chapters 2 through 4 may skip directly to the case studies.

The first case study, described in chapter 5, provides estimates of the economic impacts from past BFRL research leading to the introduction of the ASHRAE 90-75 standard for residential energy conservation. The energy costs of the ASHRAE 90-75 standard are compared to those of pre-1973 oil embargo energy standards. The case study estimates the energy savings from ASHRAE 90-75 modifications in single-family residences constructed over the period from 1975 through 1984. Furthermore, that part of dollar savings that appears attributable specifically to BFRL's research activities is estimated. For a two-page summary of the first case study, see section 5.1.

The second case study, described in chapter 6, provides estimates of the net dollar savings from a past research effort in the development of an improved asphalt shingle for sloped roofing. The costs of the improved shingle are compared against the costs of the traditional shingle it displaced. Net savings are computed for the actual quantity of the improved shingle that was installed during the period from 1962 to 1974. That part of dollar savings that appears attributable specifically to BFRL's research activities is estimated. For a two-page summary of the second case study, see section 6.1.

Assumptions about material life, the appropriate discount rate, the process by which the new technology diffuses to the ultimate users, and the impact of BFRL's activities on the diffusion process are necessary for carrying out the case studies. These assumptions are described in chapters 5 and 6. A sensitivity analysis for each case study provides the reader with additional background and perspective on BFRL's impact.

Chapter 7 concludes the report with a summary and suggestions for further research.

[7]Marshall and Ruegg, *Efficient Allocation of Research Funds*, pp. 19-30.

2. An Introduction to Benefit-Cost Analysis

Benefit-cost analysis is a technique for assessing the economic performance of both private- and public-sector programs. The technique can be used to indicate whether a specific expenditure should be undertaken. It can also be used to determine the appropriate size of the expenditure as well as the optimum configuration of the system, timing for installing components, and other aspects of system design. Finally, benefit-cost analysis provides the basis for conducting economic impact studies.

At the heart of any benefit-cost analysis is an economic concept referred to as the time value of money. This concept relates to the changing purchasing power of money (i.e., as a result of inflation or deflation), along with consideration of the real earning potential of alternative investments over time. The discount rate reflects the decision maker's time value of money. The discount rate is used to convert, via a process known as discounting, benefits and costs which occur at different times to a base time. Throughout this report, the term "present value" will be used to denote the value of a benefit or cost found by discounting cash flows (past, present, or future) to the base time. The base time is the date (base year) to which benefits and costs are converted to time equivalent values.

Benefit-cost analysis is simple in concept, reflecting a most elementary decision rule:

> No rational person is expected to undertake actions where anticipated costs exceed anticipated benefits.

However, from a practical standpoint, the application of benefit-cost analysis to either private- or public-sector decision problems may become quite complicated. The previous statement is based on the fact that conducting a benefit-cost analysis involves a multi-stage process. Consequently, complicating factors may enter at any stage. In some cases, complicating factors may exert a cascade effect or some other form of interdependency. If cascade effects or interdependencies are present and are not treated properly, the validity of the analysis may be called into question.

Other researchers and practitioners have suggested that a benefit-cost analysis may be divided into four stages: (1) identification; (2) classification; (3) quantification; and (4) presentation.[8] The identification stage involves identifying and listing all of the "effects" of the research effort being analyzed. In principle, this set of effects produces a checklist of all the items that should be taken into consideration. The second stage entails classifying these various effects into benefit categories and cost categories. The third stage produces year-by-year estimates of the values for each of the benefit categories and each of the cost categories. The values of the key evaluation methods (e.g., present value of net benefits, present value of net savings, benefit-to-cost ratio, savings-to-investment ratio, adjusted internal rate of return) are also calculated in this stage. The final stage is the presentation and analysis of the relevant information in a straightforward manner (i.e., in a form that clearly spells out the important assumptions underlying the analysis and the implications of those assumptions for the study's conclusions).

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[8] Anderson, Lee G., and Russell F. Settle. 1977. *Benefit-Cost Analysis: A Practical Guide*. Lexington: D.C. Heath and Company.

To ensure consistency in application and in interpretation, all of the evaluation methods described in this report are based on standard practices. These practices have been reviewed, critiqued, and adopted by a broad cross section of businesses concerned with choosing among investment alternatives. Specifically, these practices have been adopted by the American Society for Testing and Materials (ASTM).[9] They are used to calculate the values of all of the key evaluation methods. The five "standardized" evaluation methods—present value of net benefits, present value of net savings, benefit-to-cost ratio, savings-to-investment ratio, adjusted internal rate of return—used in this report are generic. The mathematical formulation, given by eqs (2.1) through (2.10), provides the vehicle for mapping benefit categories and cost categories into each of the five standardized methods. While there may be many different ways of classifying benefits and costs (i.e., classification schemes), their explicit treatment in both the mathematical formulation and the standardized methods ensures that a comprehensive and consistent coupling results between the mathematical formulation and each standardized method.

Similarity, it is important to note that how benefits and costs are classified is affected by the objective function[10] of the decision maker. This may be illustrated by comparing the perspective of a private-sector decision maker with that of a public-sector decision maker. A private-sector decision maker may not be concerned with benefits or costs which are external to the firm or industry. For example, unless there are licensing fees or royalties to be paid, the cost of any research external to the firm may be irrelevant to a private-sector decision maker. This would be true even if the external research provides the basis for the product or process innovation under analysis. Generally, this is in contrast to the public-sector decision maker who must assess all benefits and costs to whomsoever they accrue. Both the mathematical formulation and the standardized methods used in this report are flexible enough to deal with differences in perspective. Any differences in perspective affect only the way in which benefits and costs are classified (i.e., what is included and what is excluded). Consequently, once the perspective is defined and the classification scheme is set, the mathematical formulation and standardized methods take over, permitting an analysis which is both comprehensive and consistent.

2.1 Identifying and Classifying Benefits and Costs

Once the appropriate evaluation methods have been chosen, the analyst must identify and classify benefits and costs. Both the benefits and costs of research are multifaceted. Benefits of public-sector research may take the form of new technologies which enable new markets and products to be established. Similarly, public-sector research may lead to products which lower the costs of ownership to consumers, exhibit increased durability and reliability, and result in fewer accidents. Private-sector research tends to be product and/or process focused. In the private-sector, greater emphasis is placed on key market drivers, such as cost and quality considerations, with an aim of increasing market share rather than on research *per se*. Alternatively, one may distinguish between public-sector research and private-sector research as a movement away from basic research, which is freely shared, towards proprietary research, which is closely held and where access is controlled.

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[9] American Society for Testing and Materials (ASTM). 1994. *ASTM Standards on Building Economics*. Philadelphia, PA: American Society for Testing and Materials.

[10] An objective function is that combination of decision variables (e.g., the price and quantity sold of a line of products and the quantity and per unit cost of labor, materials, equipment, and plant and facilities used to produce that line of products) whose value is to be optimized (e.g., profit maximization or cost minimization) subject to the constraints (e.g., a budget limitation) of the problem under analysis.

Benefits tend to be more difficult to identify, classify, and quantify than costs. By and large, the majority of a research effort's costs are incurred early in its life. These costs are often well known and available from multiple sources (e.g., planning documents, budget documents, and annual reports). Benefits in the form of new products and processes stemming from the research effort occur "downstream," often many years later. The way in which any "new technology" diffuses exerts a profound influence on the timing and level of benefits.

Table 2-1 provides a comprehensive list of benefits associated with research investments. Some of the benefits recorded in the table may overlap if a specific research investment is to be evaluated. For example, the greater durability of 235 shingles results in lower operations, maintenance, and repair costs for building owners. Note that many of the benefits are in the form of cost savings.

The table lists three types of organizations as "beneficiaries" of a research investment: (1) research organizations; (2) practitioners; and (3) others. Research organizations are those entities which perform the research in the first place, collaborate in the research effort via consortia, or make use of the research findings in their independent research program. The heading, research organizations, covers the following research entities: (1) NIST/BFRL; (2) private sector firms; (3) academe; (4) professional societies and trade associations; and (5) miscellaneous public sector agencies.

Practitioners are those who employ the research findings to produce products or provide services. Three types of practitioners are listed in table 2-1: (1) manufacturing and service industries; (2) the construction industry; and (3) building owners/managers/operators. The first type, manufacturing and service industries, ensures that the table captures all forms of "productive" economic activity. Since the first type is all inclusive, it may be subdivided in any way which the analyst chooses. For example, instead of the construction industry heading and the building owners/managers/operators heading, the analyst could focus on a specific industry. The specific industry could be based on the standard industrial classification (SIC) code for that industry (e.g., SIC code 36: electrical/electronic equipment manufacturers, or SIC code 48: communications services) or some other SIC-like classification scheme. The second heading under practitioners is the construction industry, since this research project is focused on evaluating the impacts of building- and fire-related technologies. This heading includes all firms whose primary activity is construction. The construction industry is often divided into four sectors: (1) residential; (2) commercial/institutional; (3) industrial; and (4) public works. The construction industry also includes specialty contractors who support prime contractors across all four sectors. Building owners/managers/operators are covered under the third heading under practitioners. Their primary activities are service oriented.

The last "beneficiary" of a research investment, labeled "others" in the table, is those businesses/individuals which occupy the building as well as third parties who may be affected by the various research organizations, practitioners, or building occupants.

Table 2-1. Sample List of the Benefits Associated with Research

Type of Benefits or Cost Saving	Research Organizations	Practitioners			Others	
		Manufacturing and Service Industries	Construction Industry	Building Owners/ Managers/ Operators	Building Occupants	Third Parties
Adaptive Reuse				✔	✔	✔
Cycle Time Reduction	✔	✔	✔	✔	✔	✔
Diffusion Process	✔	✔	✔	✔	✔	✔
Energy Conservation				✔	✔	✔
Improved Health and Safety	✔	✔	✔	✔	✔	✔
Improved Measurement Technology	✔	✔	✔			
Improved Standards	✔	✔	✔	✔	✔	✔
Increased Durability				✔	✔	✔
Increased Licensing Fees	✔					
Increased Productivity		✔	✔	✔	✔	
Increased Reliability		✔	✔	✔	✔	✔
Increased Royalties	✔					
Increased Sales		✔	✔	✔		
Input Substitution		✔	✔	✔		✔
Reduced Property Losses				✔	✔	✔
Reduced Rework		✔	✔	✔		
Reduced Scrap		✔	✔	✔		✔
Reduced Variability		✔	✔	✔		
Reductions in Acquisition Costs				✔	✔	
Reductions in Operations, Maintenance, and Repair Costs		✔	✔	✔	✔	
Reductions in Waste and Pollution	✔	✔	✔	✔	✔	✔

Table 2-1 is laid out as a check list. Each column records information on the beneficiaries of a research investment. Each row records a generic type of benefits associated with a research investment. The generic types of benefits are listed in alphabetical order. No effort has been made to prioritize the importance of each generic type of benefits, since the specifics of the research investment under analysis is likely to govern the importance of each of the types listed in the table. The "cells" of the table represent a unique combination of the specific beneficiary and the generic type of benefits. If a generic type of benefits is important to a specific beneficiary, then a check mark (✓) is recorded in that cell of the table.

While most of the generic types of benefits listed in table 2-1 are self evident, it is useful to examine five of them in some detail. The five generic types are: (1) cycle time reduction; (2) diffusion process; (3) input substitution; (4) improved health and safety; and (5) reduced property losses. We chose these for additional discussion because their impacts are less evident and are likely to be substantial.

Cycle time reduction is present when a given task can be completed in a shorter period of time. Cycle time reduction is important to all of the beneficiaries recorded in the table. Common targets for cycle time reduction are the time to introduce new products or services, the time to produce a working prototype of an invention or an innovation, and the time to deliver a new building (i.e., the time from the decision to construct a new building until it is ready for occupancy). Process mapping, process simplification, and scheduling techniques are tools commonly used to reduce cycle time for research and other types of projects.

Earlier it was stated that the diffusion process exerted a strong influence on the benefit stream. Basically, there are three ways in which the diffusion process affects the benefit stream. To better understand these three ways, consider the case of a product innovation. The first way concerns the time to "first use" of the innovation. Speeding up the time to first use means that the beneficiaries will begin to receive benefits or cost savings from the innovation earlier than would have been possible otherwise. The second way concerns the rate of adoption. If the contribution of the research organization is to increase the rate of adoption in any single year or across a number of years, say due to its prestige as the source of the innovation, then benefits and cost savings will accrue at a faster rate than otherwise in those years. The third way concerns the ultimate level of adoption (i.e., how completely the innovation penetrates the market). If the ultimate level of adoption is higher, then the overall potential magnitude for benefits and cost savings is increased. Because both the timing and the magnitude of the benefit stream is important in the calculation of the present value of benefits or the present value of savings, other things being equal, speeding up the time to first use, increasing the rate of diffusion, or increasing the ultimate level of adoption results in an increase in benefits. Reference to the table shows that the diffusion process is important to all beneficiaries.

Input substitution is the subject of a vast literature on technological change. Readers interested in a comprehensive and rigorous treatment of technological change are referred to the book by Stoneman.[11] To illustrate this important concept, consider the case of a process innovation. Successful process innovations make it possible to produce the same level of output with fewer inputs from one or more factors of production (e.g., a specific material or chemical). If these factor inputs cost the same as before, the firm's production costs are lowered. Alternatively, the new production process may enable the firm to substitute cheaper inputs for more expensive ones. The result is, once again, a reduction in production

[11]Stoneman, Paul. 1983. *The Economic Analysis of Technological Change*. New York: Oxford University Press.

costs. Furthermore, if one or more of the inputs is deemed to be "hazardous," third parties may expect to receive benefits from the firm's decision to substitute more environmentally "friendly" inputs for those deemed to be hazardous.

The last two generic types of benefits are safety related. They are a motivating factor behind regulations aimed at occupational health and safety as well as many building codes and standards. The first, increased health and safety, applies to all beneficiaries, workers, building occupants, and third parties. Construction worker safety, aimed at fewer accidents (e.g., loss of life and limb), is an important goal for the construction industry. A second construction industry goal is to reduce property losses. A key dollar measure for both safety-related issues is expected reductions in both insurance costs and out-of-pocket losses. In the construction industry where specific compliance measures often need to be undertaken, a new technology may manifest itself in a new building code or standard. If such a code or standard is performance-based, it may result in equivalent levels of safety at reduced costs of compliance. This performance-based approach to safety is a major emphasis of BFRL's research program. The companion document includes a case study of a performance-based approach to fire safety in health care facilities.[12]

Key benefits accruing to the building owner/manager due to the adoption and use of innovative building materials and technologies include reductions in delivery time (i.e., reduction in the time from the decision to construct a new building to its readiness for occupancy) as well as reductions in the costs of construction, use, and disposal. For a detailed analysis of the economics of innovative building materials, see Ehlen and Marshall.[13] Additional benefits include increased rental income (e.g., due to better amenities), adaptive reuse (e.g., the ability to accommodate different configurations of office space) which may result in higher occupancy rates and the ability to easily renovate the interior space for completely new types of occupancy. The latter subject is emerging as a means for efficiently renovating buildings to accommodate organizational and technological change.[14] Key benefits accruing to building occupants and third parties include reductions in waste and pollution through use of environmentally-friendly materials and technologies, improved occupant health and safety (e.g., reductions in occupant-related illnesses and injuries) and increased productivity and comfort (e.g., better lighting, layouts which facilitate communication, etc.).

Table 2-2 provides a format for classifying costs associated with research, including innovations stemming from that research. The organizations bearing the costs are patterned after the "beneficiaries" in table 2-1. The organizations bearing the costs are: (1) research organizations; (2) practitioners; and (3) others. The key types of costs shown in table 2-2 are listed hierarchically under primary and secondary levels.

Costs may be classified as in table 2-2, or into one of two broad categories: (1) investment; and (2) non-investment. The latter classification scheme is used here.

[12]Chapman and Weber, *A Case Study of the Fire Safety Evaluation System.*

[13]Ehlen, Mark A., and Harold E. Marshall. 1996. *The Economics of New-Technology Materials in Construction: A Case Study of Composite Bridge Decking*. NISTIR 5864. Gaithersburg, MD: National Institute of Standards and Technology.

[14]For a good discussion on building reuse, see, Loftness, Vivian, Jack J. Beckering, William L. Miller, and Arthur Rubin. *Re-valuing Buildings. S5927. Grand Rapids, MI: Steelcase Inc.*

Table 2-2. Sample Classification of the Costs Associated with Research

Type of Organization Bearing the Costs	Type of Cost	
	Primary Level	Secondary Level
Research Organization	Labor Salaries, Training, and Travel	Researchers Technicians Managers Contract Workers on Site Support, Administrative, and Secretarial Staff
	Capital Expenses	Site and Facilities Laboratory Equipment Computer Equipment Laboratory Materials
	Operation, Maintenance, and Repair of Facility and Equipment	
	Contract Costs for Technical Work Done by Others	
	Dissemination Costs	Printing/Publishing Research Results Distribution Standards and Professional Society Activities Other Meetings to Link to Industry World Wide Web
Practitioners	Training for Using the Innovation	
	Adapting the Innovation to Industry Use	
	Investments in New Equipment/Materials/Processes	
Others	Spillovers	

The distinction between investment and non-investment costs is important because the decision maker is assumed to maximize the return on investment costs. For example, if the benefit-cost analysis were conducted from the perspective of a public-sector laboratory research director versus that of a private-sector business executive, the way in which each would classify investment and non-investment costs might differ significantly. A public-sector laboratory research director would consider research expenditures (e.g., labor, purchase of specialized facilities/equipment/materials, contracts and the like) and the costs of diffusing the research as investment costs and the costs of launching and producing products, and any consumer-related expenses as non-investment costs. On the other hand, a private-sector business executive would consider as investment costs the firm's costs for product-related research, its cost of establishing a delivery system, and its capital expenditures for plant and equipment to produce the product. Non-investment costs would include the costs of producing and delivering the product, and operations, maintenance and energy costs for physical plant and equipment (e.g., energy, water, maintenance and repairs, taxes, insurance, etc.).

2.2 Mathematical Formulation

Once all benefits and costs have been identified and classified, it becomes necessary to develop year-by-year estimates for each of the benefit and cost categories for each alternative system under analysis. If we denote alternatives as a (where the index for a ranges from $1,...,A$), benefit (B) categories as j (where the index for j ranges from $1,...,J^a$), investment cost (I) categories as k (where the index for k ranges from $1,...,K^a$), non-investment cost (C) categories as m (where the index for m ranges from $1,...,M^a$), and time as t (where the index for t ranges from $-t^a,...,0,...,T$), then the benefits and costs for alternative a^* in year t may be expressed as:

$$B_t^{a^*} = \sum_{j=1}^{J^{a^*}} B_{jt}^{a^*} \tag{2.1}$$

$$I_t^{a^*} = \sum_{k=1}^{K^{a^*}} I_{kt}^{a^*} \tag{2.2}$$

$$C_t^{a^*} = \sum_{m=1}^{M^{a^*}} C_{mt}^{a^*} \tag{2.3}$$

where $a*$ = the alternative under analysis;

J^{a*} = the number of benefit categories associated with alternative $a*$;

K^{a*} = the number of investment cost categories associated with alternative $a*$; and

M^{a*} = the number of non-investment cost categories associated with alternative $a*$.

The combined costs ($\overline{C}$) for alternative a* in year t may now be expressed as:

$$\overline{C_t^{a^*}} = I_t^{a^*} + C_t^{a^*} = \sum_{k=1}^{K^{a^*}} I_{kt}^{a^*} + \sum_{m=1}^{M^{a^*}} C_{mt}^{a^*} \tag{2.4}$$

The savings (S) from alternative $a*$ in year t may be designated as:

$$S_t^{a^*} = B_t^{a^*} - C_t^{a^*} \tag{2.5}$$

Equations (2.1) through (2.5) provide the basis for calculating the present value of benefits (PVB), the present value of investment costs (PVI), the present value of non-investment costs (PVC), the present value of combined costs (PV$\overline{C}$), and the present value of savings (PVS) for each alternative. These values for alternative $a*$ are defined by eqs (2.6) through (2.10), respectively, as:

$$PVB^{a^*} = \sum_{t=-t^{\alpha}}^{T} \left(\sum_{j=1}^{J^{a^*}} B_{jt}^{a^*} \right) / (1+d)^t \tag{2.6}$$

$$PVI^{a^*} = \sum_{t=-t^{\alpha}}^{T} \left(\sum_{k=1}^{K^{a^*}} I_{kt}^{a^*} \right) / (1+d)^t \tag{2.7}$$

$$PVC^{a^*} = \sum_{t=-t^{\alpha}}^{T} \left(\sum_{m=1}^{M^{a^*}} C_{mt}^{a^*} \right) / (1+d)^t \tag{2.8}$$

$$\overline{PVC^{a^*}} = \sum_{t=-t^{\alpha}}^{T} \left(\sum_{k=1}^{K^{a^*}} I_{kt}^{a^*} + \sum_{m=1}^{M^{a^*}} C_{mt}^{a^*} \right) / (1+d)^t \tag{2.9}$$

$$PVS^{a^*} = \sum_{t=-t^{\alpha}}^{T} \left(\sum_{j=1}^{J^{a^*}} B_{jt}^{a^*} - \sum_{m=1}^{M^{a^*}} C_{mt}^{a^*} \right) / (1+d)^t \tag{2.10}$$

where d = the discount rate;

$-t^{\alpha}$ = the number of years before the base year (i.e., $t=0$) for which benefits and costs accrue[15] for alternative a^*; and

T = the last year of the study period.

The mathematical formulation given in eqs (2.1) through (2.10) is general in scope. This was done to make explicit four key concepts and to serve as a point of departure for the remainder of the report. First, for a given alternative (e.g., for alternative a^*), the number of benefit categories need not equal the number of cost categories. This key concept is shown through the use of three indexes, j, k, and m, respectively. Second, for different alternatives, the number of benefit categories and the number of cost categories need not be equal. This key concept is shown by the a^* superscript on the maximal member of the j, k, and m indexes, respectively. Obviously, there will be cases where, for different alternatives, the number of cost and benefit categories will be both equal in number and the same in definition. The formulation given by eqs (2.1) through (2.10) allows for identical categories but does not require them. Third, the time dimension is explicit. Key times during the study period are shown as $-t^{\alpha}$, 0, and T, respectively; the length of the study period is defined as $t^{\alpha}+T$. Finally, all annual benefits, investment costs, non-investment costs, combined costs, and savings are explicit in the formulation, both as components (i.e., for each category) and as aggregates (i.e., the sum total for a given year).

The four stage "process flow," outlined at the beginning of this chapter, coupled with eqs (2.1) through (2.10) provide a conceptual and mathematical framework for the remainder of the report. The first two stages of the process flow, identification and classification of each alternative's benefits and costs, are the focus of section 2.1. The challenges associated with quantifying each alternative's benefits and costs, the third stage of the process flow, are the focus of sections 2.3. and 2.4. An overview of the fourth stage of

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[15] The term $-t^{\alpha}$ is used to designate the earliest point before the base year across all alternatives for which benefits and costs accrue. The alternative, say a^*, which results in $-t^{\alpha}$ and T, the last year in the study period, specify the length of the study period for all alternatives.

the process flow, presentation and analysis of results, is the focus of chapter 4. The key evaluation methods are described and summarized in chapter 3. Each key evaluation method (e.g., benefit-to-cost ratio) is derived through reference to eqs (2.1) through (2.10). Chapters 5 and 6 illustrate how to apply in practice the framework and standardized methods described in chapters 2 through 4. Special emphasis is placed on the fourth stage of the process flow, presentation and analysis of results. Chapter 7 provides a summary and suggestions for further research.

2.3 Technical Considerations

2.3.1 Setting the Discount Rate

The economic literature on setting the discount rate for public and private investments is both vast and complex. A good overall coverage of the subject is given in Ruegg and Marshall.[16] The discussion which follows closely parallels the treatment found in Ruegg and Marshall.

The discount rate, or minimum attractive rate of return, imposes a condition of minimum profitability which a project must meet to qualify for acceptance. Because it affects whether a project will be accepted or rejected and how much will be spent on it, the value of the discount rate is a key ingredient in a benefit-cost analysis. If it is set too high, some projects which are economical will be rejected; if too low, some projects which are uneconomical will be accepted.

The discount rate should reflect the rate of return available on the next best investment opportunity of similar risk to the project in question. The numerical value of the discount rate should reflect the "opportunity cost" that investors experience when they forego the return on the next best investment to invest in a given project. The analysis of private-sector decision making—businesses and households—requires the use of an after-tax discount rate.

Firms often compute and use the weighted average cost of capital as their discount rate. The rate in this case is based on the average cost of past funds acquired. The weighted marginal cost of capital, however, is a more correct measure of the discount rate. It is based on the costs of acquiring the last dollar of new capital. If securing additional funding does not change the proportions of debt and equity (i.e., their weights) or the costs of each, the weighted marginal cost of capital will be the same as the weighted average cost of capital. If the proportion of debt increases, this may cause the market price of the firm's stock to drop, thereby raising the cost of equity funds.

The weighted (average or marginal) cost of capital is computed by finding the after-tax cost of each source of funding to the firm—equity and debt issue—and applying weights based on the proportion of funds obtained from each source. The weighted average cost of capital reflects the average riskiness of the firm's past activities; the weighted marginal cost of capital reflects the average riskiness of incremental activities. The rationale for using the weighted (average or marginal) cost of capital as the discount rate is as follows: the firm must obtain an overall yield on its investments at least sufficient to cover its cost of capital in order to prevent the market price of its outstanding securities from falling.

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[16] Ruegg, Rosalie T., and Harold E. Marshall. 1990. *Building Economics: Theory and Practice*. New York: Chapman and Hall, Inc., pp. 153-167.

Discount rates influence the allocation of public funds and are therefore important tools of public policy. In the United States, specification of discount rates for evaluating public projects dates from the 1930s, when Federal agencies were directed to discount the benefits and costs of water resources projects.

It is widely agreed by economists that the appropriate discount rate for evaluating public investments is a rate set to maximize net social benefits. Thus the rate is often called the "social discount rate." This view, and term, gained favor in the 1960s as an aspect of welfare economics. What should be the appropriate numerical value of the discount rate, or rates, for evaluating public investments is, however, a topic of controversy and on-going debate. It is a complex question with many unresolved issues.

Guidance in setting the discount rate for federal agencies comes from two sources. For energy and water conservation and renewable resource projects under the Federal Energy Management Program, the U.S. Department of Energy has legislative authority to establish the appropriate discount rate using the procedure specified in *10 CFR 436*. For all other cases, the Office of Management and Budget (OMB) *Circular A-94* provides guidance on the discount rates to be used in evaluating government programs whose benefits and costs are distributed over time.

2.3.2 Defining the Base Case

Before continuing further, it is helpful to state the basis upon which the benefits, costs, and savings of an alternative are estimated. Estimates for an alternative, a^*, may be derived in one of three ways. Each way has a specific reference point, referred to as the base case. The three ways for defining the base case are: (1) as a completely stand alone project; (2) as an alternative to the *status quo*; and (3) as a mutually exclusive course of action. Estimates for the first way, a stand alone project, are fairly straightforward. Estimates for the second and third ways are also fairly straightforward. A specific, mutually exclusive alternative to a^* is maintenance of the *status quo*. Thus the second way of deriving estimates and its reference point—maintenance of the *status quo*—is a subset of the third. Additional information on maintenance of the *status quo* and on mutually exclusive alternatives is given in section 2.3.3. Detailed discussions on how the base case is defined in practice are given for each of the case studies presented in chapters 5 (see section 5.2) and 6 (see section 6.2).

Two additional factors are associated with the base case; these factors also apply to any alternative under consideration. The two factors are: (1) the length of the study period; and (2) the base year to be used for computing time-equivalent values for all costs, benefits, and savings.

2.3.2.1 Determining the Length of the Study Period

The study period is constructed to include all relevant costs, benefits, and savings associated with the alternatives under consideration. In order to promote consistency when comparing more than one alternative, the study period begins at the earliest point for which costs, benefits, and/or savings accrue and ends at the latest point for which costs, benefits, and/or savings accrue. Throughout this report, the length of the study period is defined to be L years. To better understand the mechanics of determining the length of the study period, consider the specific case of ASHRAE 90-75.

In the case of ASHRAE 90-75, presented in chapter 5, the base case is the adoption of ASHRAE 90-75 as an alternative to the *status quo*. BFRL's ASHRAE 90-75-related research investments began in 1973.

Energy conserving investments in single-family residences, based on BFRL's ASHRAE 90-75-related research, began in 1975. All energy conserving investments in single-family residences, based on BFRL's ASHRAE 90-75-related research, were assumed to end in 1984. All energy conserving investments made during the period 1975 through 1984 were assumed to generate cost savings for a period of 10 years after their installation, implying that the study period ends in 1994. The study period begins in 1973, when BFRL's research effort began, and ends in 1994, when the last year's worth of energy cost savings were assumed to accrue. The length of the study period is therefore 22 years.

2.3.2.2 Determining the Base Year

In order to establish a time-equivalent set of values for costs, benefits, and savings, it is necessary to specify a base year. The base year may be in the past, in the present, or in the future. While there is considerable latitude in choosing the base year, it must be within the study period.[17] Focusing our attention on the study period, which spans L years, we see that three possibilities for placement of the base year arise. These possibilities are: (1) at the beginning of the study period; (2) at the end of the study period; and (3) in between the beginning and the end of the study period. The three possibilities are illustrated in figures 2-1, 2-2, and 2-3, respectively.

In examining these three possibilities, it is important to keep the following key points in mind: (1) the choice of the base year is partly a convenience for performing calculations and partly a reflection of organizational guidelines; (2) all three possible placements are acceptable; and (3) once a base year has been chosen, all calculations for all alternatives under consideration must use it. The first key point is of particular importance because the discount rates referred to in this report are real.[18] Consequently, all dollar values are real, meaning their values—both discounted and undiscounted—are expressed in base year dollars. Throughout this report, the time index associated with the base year is equal to zero (i.e., t=0).

Case 1: Base Year at the Beginning of the Study Period

Figure 2-1 illustrates this case. Two end points, spanning L years, are shown in the figure. The beginning of the study period and the base year coincide. The time index ranges from t=0, for the base year, to $t=L$, for the end of the study period. All present value calculations are expressed as time-equivalent values occurring at the beginning of the study period (i.e., at t=0).

[17] If the economic impact study is of an *ex post* nature where all costs, benefits, and savings are in the past (i.e., the end of the study period is in the past), the base year must still be within the study period. In such cases, however, it is desirable to record the values of the key evaluation methods denominated in both base year dollars and current year dollars. This approach is employed in the two case studies presented in chapters 5 and 6.

[18] Recall that discount rates reflect the investor's time value of money (or opportunity cost). Real discount rates reflect time value apart from changes in the purchasing power of the dollar (i.e., inflation or deflation) and are used to discount real dollar (constant dollar) cash flows. Real dollars are dollars of uniform purchasing power tied to a specified time (i.e., the base year). Nominal discount rates include changes in purchasing power of the dollar and are used to discount current dollar cash flows. Current dollars are dollars of nonuniform purchasing power, in which actual prices in the market are stated for a given time. With no inflation or deflation, current dollars are identical to real dollars.

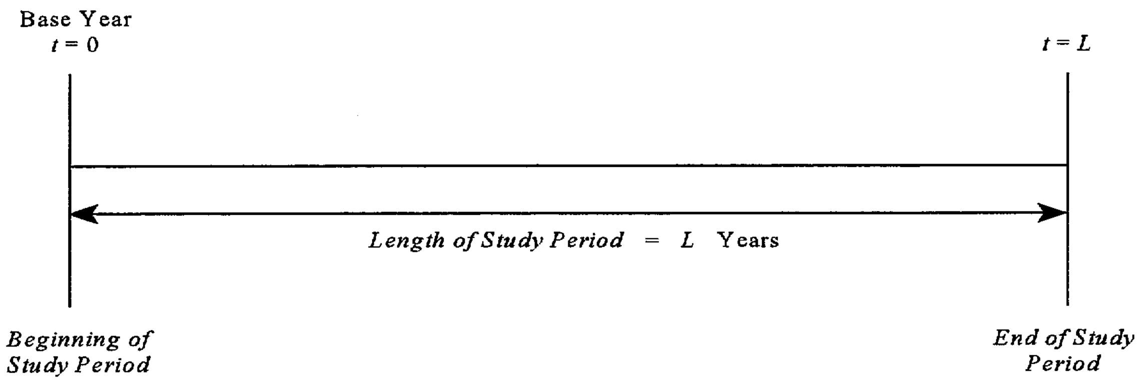

Figure 2-1. Base Year at the Beginning of the Study Period: Relationship Between Base Year and the Length of the Study Period

An advantage of this placement of the base year is that the notation is simpler than that of section 2.2. Furthermore, many text books employ this approach.[19] A potential disadvantage is that benefits and savings associated with research investments occur after the research is undertaken. In some cases, the delay may be 10 years or more. For example, in *ex ante* analyses, investment costs may be known but potential benefits and savings are subject to considerable uncertainty.

Case 2: Base Year at the End of the Study Period

Figure 2-2 illustrates this case. Two end points, spanning L years, are shown in the figure. The end of the study period and the base year coincide. The time index ranges from t=-L, for the beginning of the study period, to t=0, for the base year. All present value calculations are expressed as time-equivalent values occurring at the end of the study period. In this case, all costs, benefits, and savings are brought forward (i.e., compounded) to the base year at the end of the study period.

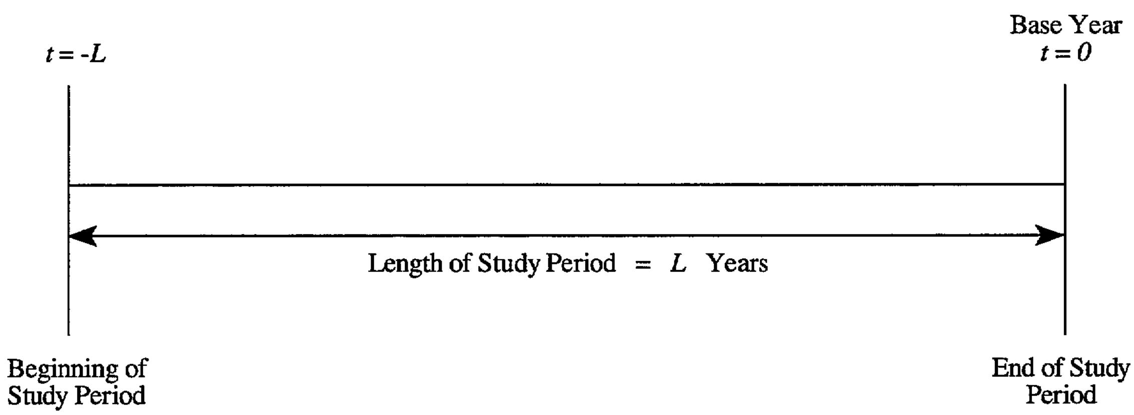

Figure 2-2. Base Year at the End of the Study Period: Relationship Between Base Year and the Length of the Study Period

[19]For a good discussion on placement of the base year at the beginning of the study period, see Ruegg and Marshall, *Building Economics*, pp. 34-91.

The notation associated with the placement of the base year at the end of the study period is simpler than that of section 2.2 but more complex than that associated with the placement of the base year at the beginning of the study period. Placement of the base year at the end of the study period is ideal for *ex post* studies where information on benefits and savings are well documented. The placement of the base year at the end of the study period is employed in chapter 6, where the case study of 235 shingles is presented.

Case 3: Base Year is in Between the Beginning and the End of the Study Period

Figure 2-3 illustrates this case. Two sets of end points, one spanning t^{α} years—from $t=-t^{\alpha}$ to $t=0$—and one spanning T years—from $t=0$ to $t=T$, are shown in the figure. The two sets of end points span the length of the study period, L years. This placement of the base year mirrors the exposition in section 2.2; the time index ranges from $t=-t^{\alpha}$, at the beginning of the study period, to $t=T$, at the end of the study period. All present value calculations are expressed as time-equivalent values occurring in the base year.

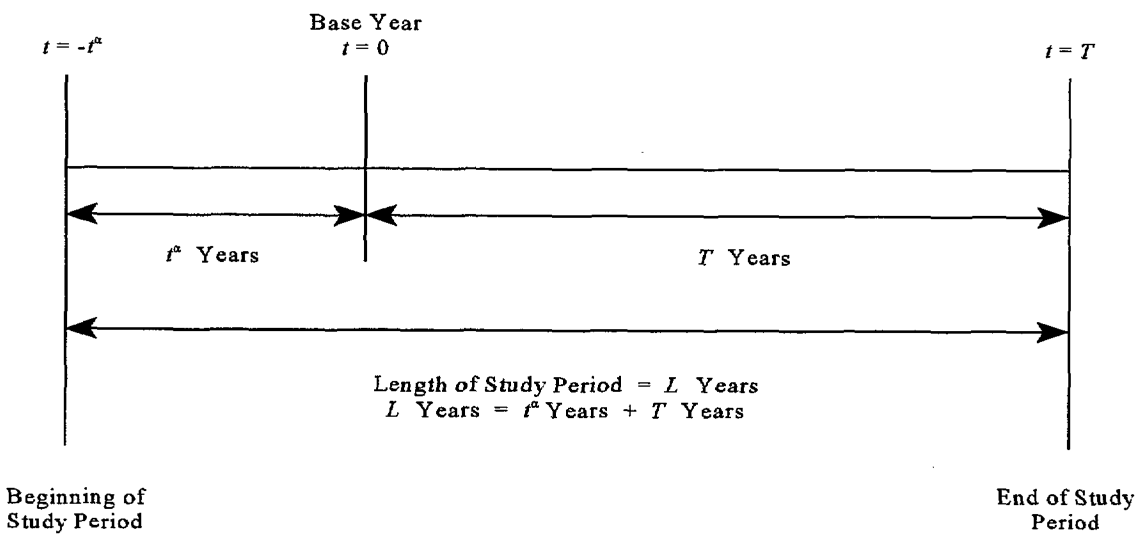

Figure 2-3. Base Year in Between the Beginning and the End of the Study Period: Relationship Between Base Year and the Length of the Study Period

This notation is advantageous, since it permits the most general formulation. Both cases described earlier may be formulated as special cases (e.g., by setting $-t^{\alpha}$ to 0 and T to L or by setting $-t^{\alpha}$ to $-L$ and T to 0). This notation provides the basis for deriving the standardized practices in chapter 3. Such a placement of the base year is ideal for *ex post* analyses where extensive use is made of data from published sources. For example, the case study of ASHRAE 90-75 makes extensive use of data from a study performed by Arthur D. Little in 1975.[20] Consequently, 1975 was chosen as the base year for the economic impact study of

[20] Arthur D. Little, Inc. 1975. *Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75*. Conservation Paper 43B. Arthur D. Little, Inc.

BFRL's ASHRAE 90-75-related research. Recall that BFRL's ASHRAE 90-75-related research was begun in 1973. This case study, summarized in chapter 5, has a study period which spans 22 years, from 1973 to 1994.

2.3.3 Measuring Cost Savings

Reference to the *status quo* is used here to illustrate how net savings from alternative a^* can be positive even if it does not generate any revenues. That such an outcome is possible may be understood by recognizing that maintenance of the *status quo* has associated with it both costs and benefits. The costs and benefits associated with maintenance of the *status quo* may be higher, lower, or the same as those associated with a mutually exclusive alternative, a^*. It is important to note that a benefit-cost analysis may be performed entirely based upon the differences between two mutually exclusive alternatives (e.g., the *status quo* and a^*). In such a case, the estimated values of these differences—for each benefit and cost category and for each year—become the entries on the right hand sides of eqs (2.1) through (2.10). Thus, if mutually exclusive alternative a^* has lower costs than maintenance of the *status quo*, it results in "cost savings."

Consider the special case where benefits are zero throughout the length of the study period but which, for the moment, excludes investment costs from the analysis. If non-investment costs for alternative a^* in year t are less than those of maintaining the *status quo*, then inserting these differences into eq (2.5) yields positive savings even though a^* generates no revenues. Next, consider the special case where benefits are zero throughout the length of the study period but which includes investment costs in the analysis. In this case, eq (2.9) provides the basis for choosing among mutually exclusive alternatives (e.g., the *status quo* and a^*). Upon closer examination, eq (2.9) is revealed to be equivalent to the life-cycle costs of alternative a^*, denoted henceforth as LCC^{a^*}. If the life-cycle costs of alternative a^* are less than those of maintaining the *status quo*, then investment in alternative a^* generates positive net savings even though it generates no revenues. The use of life-cycle costs is a widely-accepted evaluation method.[21]

To better understand how life-cycle costs may be used to measure cost savings, consider the following simplified example. A manufacturer produces electronic control units for use in commercial office buildings. The manufacturer has experienced production problems which result in unusually high levels of scrap and rework of the electronic control unit's component parts. Research on the design and manufacturing processes for this electronic control unit has resulted in a new type of sensor which permits more frequent and more accurate measurements to be taken during the manufacture of each component part.

If installed, the "in-process" measurements taken by the new sensor technology will reduce both scrap and rework by catching problems earlier than was possible with the old sensor technology. However, in order for the manufacturer to reduce the costs of scrap and rework, it will be necessary to remove some or all of the old sensors and install the new ones. The present value of investment costs for each of four different levels of investment in the new sensor technology are summarized in column (1) of table 2-3. The four levels of investment are: (1) do not install the new sensor technology (i.e., maintenance of the *status quo*); (2) install the new sensor technology only for those components with "unacceptably" high rates of scrap

[21] American Society for Testing and Materials (ASTM). 1993. *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems.* E 917. Philadelphia, PA: ASTM.

Table 2-3. Using Life-Cycle Costs to Measure Cost Savings

Level of Investment	Present Value of Investment Costs (1)	Present Value of the Costs of Scrap and Rework (2)	Present Value of Life-Cycle Costs (3)	Present Value of Net Savings (4)
(1)	0	100	100	0
(2)	10	80	90	10
(3)	20	65	85	15
(4)	80	25	105	-5

and rework; (3) install the new sensor technology for level (2) components and those components with the highest value added; and (4) install the new sensor technology for all components.

To keep the example simple, we assume that the costs of employing the new sensor technology (e.g., taking and analyzing the measurements) are the same as for the old sensor technology. The costs of scrap and rework, however, are reduced as more of the new sensor technology is installed on the production line. The present value of the costs of scrap and rework are summarized in column (2) of table 2-3.

The life-cycle costs (i.e., the sum of the present value of investment costs and the present value of the costs of scrap and rework) for each of the four levels of investment in the new sensor technology are summarized in column (3) of table 2-3. The difference between the life-cycle costs of level (1), $LCC^{(1)}$, and each of the investment alternatives is shown in column (4) of table 2-3. This difference is referred to as the present value of net savings.

Reference to table 2-3 reveals that investment in either level (2) or level (3) of the new sensor technology is justified, since it results in positive net savings (i.e., the investment is cost effective). Investment in level (3) generates the greatest net savings. Investment in level (4) is not justified, since its life-cycle costs are higher than maintenance of the *status quo* (i.e., $LCC^{(4)} > LCC^{(1)}$).

2.3.4 Quantification and Data Issues

Quantification, the third step in the four-step process, is often the most difficult. Facts and data are of central importance here because they should be the basis for estimating all project benefits, costs, and savings. A study which lacks a strong foundation of data and other factual information will produce weak or inconclusive results.

Data sources are many and varied. Consequently, a strategy for data collection and analysis should be developed early in the analysis. Whenever possible, published data or information from professional

societies or trade associations should be used. In addition to these sources, the economics profession has a long history in the areas of benefit-cost analysis and technological change. The ***Journal of Economic Literature (JEL)*** is an excellent source for accessing this literature. The ***JEL***'s classification system for journals and articles in the areas of Economic Welfare, D6, and Technological Change, O3, is a good starting point.

To illustrate sources for benefit, cost, and savings data, consider the specific case of building- and construction-related projects. Issues which are of key importance here concern construction, maintenance and repair, energy prices, and rental income. Published data sources associated with each issue are summarized in table 2-4. The table is based largely on material presented in Ruegg and Marshall.[22]

Table 2-4. Sample Published Data Sources

Type of Cost or Benefit	Sample Published Data Source
Construction	*Means Building Construction Cost Data Book.* Kingston, MA: R.S. Means Company, Inc.
Maintenance and Repair	*Building Maintenance, Repair, and Replacement Database (BMDB) for Life-Cycle Cost Analysis.* Philadelphia, PA: American Society for Testing and Materials (ASTM). *The Downtown and Suburban Office Building Experience Exchange Report (EER).* Washington, DC: Building Owners and Managers Association International (BOMA).
Energy Prices	
Public-Sector Organizations	*Life-Cycle Manual for the Federal Energy Management Program.* NIST Handbook 135. Gaithersburg, MD: National Institute of Standards and Technology.
Private-Sector Organizations	*Comprehensive Guide for Least-Cost Energy Decisions.* NBS Special Publication 709. Gaithersburg, MD: National Bureau of Standards.
Rental Income	*EER.* Washington, DC: BOMA.

For large projects, a standard format for organizing construction cost data is desirable. Such a format assists in the retrieval of information and promotes understanding by others who may wish to use or review the data. In the United States, the Construction Specification Institute publishes a Manual of Practice which

[22]Ruegg and Marshall, *Building Economics, pp. 168-185.*

provides a masterlist of titles and numbers for organizing construction information. It is called MASTERFORMAT. It is a functional-oriented cost system and provides for organizing construction cost estimates into 16 divisions. Better for the purpose of building design and cost comparison and analysis is a systems or elemental approach to formatting cost data. The American Society for Testing and Materials' standard classification for building elements and related sitework, called UNIFORMAT II,[23] is such a system. It organizes costs into three levels for each of seven major groups.

Additional information on benefits, costs, and savings associated with construction-related projects is being produced as part of the National Construction Goals initiative of the National Science and Technology Council Subcommittee on Construction and Building. One part of this multi-pronged initiative is to produce baselines and measures of progress towards achieving each of the seven National Construction Goals. These data, once developed and disseminated, will be a valuable source of information on the impacts of construction-related research. Specifically, they will make it possible to demonstrate the benefits of advanced construction technologies and practices.

2.4 Sensitivity Analysis: A Tool for Dealing with Uncertainty

There are a variety of techniques for dealing with uncertainty in a benefit-cost analysis. Among the most commonly used are: (1) breakeven analysis;[24] (2) conservative benefit and cost estimating;[25] (3) decision analysis;[26] and (4) sensitivity analysis. In general, these methods are not limited to benefit-cost analysis and may be used for any form of economic analysis. The discussion in this section focuses primarily on one of these methods, sensitivity analysis. Readers interested in a comprehensive survey on methods for dealing with uncertainty for use in government and private-sector applications are referred to the study by Marshall[27] and the subsequent video[28] and workbook.[29]

Sensitivity analysis measures the impact on project outcomes of changing the values of one or more key input variables about which there is uncertainty. Sensitivity analysis can be performed for any measure of economic performance (e.g., present value of net benefits, present value of net savings, benefit-to-cost ratio, savings-to-investment ratio, adjusted internal rate of return). Since sensitivity analysis is easy to use

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[23] American Society for Testing and Materials (ASTM). 1993. *Standard Classification for Building Elements and Related Sitework—UNIFORMAT II.* E 1557. Philadelphia, PA: ASTM.

[24] Breakeven analysis is a method for determining the minimum or maximum value that a particular variable can reach and still have a breakeven project (i.e., a project where benefits (savings) equal costs).

[25] Conservative benefit and cost estimating is a simplistic approach to accounting for the uncertainty of selected variables. The values of these "input" variables are chosen so that any errors due to uncertainty will result in an underestimation of the project's economic worth. This is accomplished by intentionally estimating benefits on the low side, costs on the high side, or both. Alternatively, when estimating the values of parameters on which benefits and costs depend (e.g., project life), the parameter estimates would be made in the direction that lowers expected benefits and raises expected costs.

[26] Decision analysis is a method for making economic decisions in an uncertain environment that allows a decision maker to include alternative outcomes, risk attitudes (i.e., the willingness of decision makers to take chances or gamble on investments of uncertain outcome), and subjective impressions about uncertain events in an evaluation of investments. Decision analysis typically uses decision trees to represent decision problems.

[27] Marshall, Harold E. 1988. *Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Building Investments.* NIST Special Publication 757. Gaithersburg, MD: National Institute of Standards and Technology.

[28] Marshall, Harold E. 1992. *Uncertainty and Risk—Part II in the Audiovisual Series on Least-Cost Energy Decisions for Buildings.* Gaithersburg, MD: National Institute of Standards and Technology.

[29] Marshall, Harold E. 1993. *Least-Cost Energy Decisions for Buildings—Part II: Uncertainty and Risk Video Training Workbook.* NISTIR 5178. Gaithersburg, MD: National Institute of Standards and Technology.

and understand, it is widely used in the economic evaluation of government and private-sector applications. Office of Management and Budget *Circular A-94* recommends sensitivity analysis to federal agencies as one technique for treating uncertainty in input variables.

The starting point for a sensitivity analysis may be referred to as the baseline analysis. In the baseline analysis, all data (i.e., all input variables and any functional relationships among these variables) entering into the benefit, cost, and savings calculations are fixed at their expected values.[30] Alternatively, the baseline values of key input variables may be fixed at their median values.[31] Consequently, expected value, median value and baseline value may be used interchangeably. Baseline data represent a fixed state of analysis based on expected/median values. For this reason, the results and the analysis of these results are referred to as the baseline analysis. Throughout this report, the term baseline analysis is used to denote a complete analysis in all respects but one; it does not address the effects of uncertainty. Therefore, a sensitivity analysis complements the baseline analysis by evaluating the changes in output measures when selected key sets of data vary about their expected/median (i.e., baseline) values.

Sensitivity analysis may be divided into two polar cases: (1) deterministic; and (2) probabilistic. Deterministic sensitivity analyses are the most straightforward. Their advantage is that they are easy to apply and the results are easy to explain and understand. Their disadvantage is that they do not produce results that can be tied to probabilistic levels of significance (i.e., the probability that the benefit-to-cost ratio will have a value less than 1.0).

For example, a deterministic sensitivity analysis might use as inputs a pessimistic, the expected/median, and an optimistic value for the variable of interest. Then an analysis could be performed to see how the outcome measure (e.g., the benefit-to-cost ratio) changes as each of the three chosen values is considered in turn, while all other variables are maintained at their baseline values. A deterministic sensitivity analysis can also be performed on different combinations of input variables. That is, several variables are altered at once and then an outcome measure is computed. This is the approach used in the sensitivity analyses presented in chapters 5 and 6.

In a probabilistic sensitivity analysis, a small set of key input variables are varied in combination according to an experimental design. In most cases, probabilistic sensitivity analyses are based on Monte Carlo techniques, or some other form of simulation. The objective of a probabilistic sensitivity analysis is to evaluate how uncertainty in the values of key input variables translate into changes in the values of key output measures (e.g., the benefit-to-cost ratio). The major advantage of a probabilistic sensitivity analysis is that it permits the effects of uncertainty to be rigorously analyzed. For example, not only the expected value of a key output measure can be computed but also the variability of that value. In addition, probabilistic levels of significance can be attached to the computed values of key output measures. The disadvantage of a probabilistic sensitivity analysis is that it requires many calculations carried out according to an experimental design, and is therefore practical only when used with a computer.

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[30] The expected value or mean of a probability distribution is a statistical measure of central tendency. The arithmetic mean or expected value of a sample of items (e.g., per unit cost data for installing high-performance windows in a single-family home) is the sum of the individual values of the items divided by the number of items in the sample.

[31] The median of a probability distribution is a statistical measure of central tendency. The median value of a sample of items is the middle value in a rank ordering of the individual values of the items in the sample.

Model sampling provides the basis for many probabilistic sensitivity analyses. Model sampling is a procedure for sampling from a stochastic process to determine, through multiple trials, the characteristics of a probability distribution. A related procedure, known as the Latin hypercube sampling scheme, is becoming widely used, especially for cases involving complex sets of functional relationships among input variables. Readers interested in an overview of both techniques are referred to the study by Harris.[32]

Latin hypercubes, as its name implies, are patterned after the classical Latin square. Latin squares consist of a set of permutations such that a given character or value appears only once in each row and each column. A Latin hypercube is similar to a Latin square with the important exception that it contains more rows than columns. In practice, each column is an input variable and each row is a simulation number. The experimental design is therefore a table composed of cells (i.e., a unique row-column entry). The entries in the cells contain the values of a set of equally-spaced percentiles from the parent cumulative distribution function (CDF)[33] of the variable of interest. For example, if the experimental design were based on 50 simulations, the entries would correspond to a permutation of the values of the 1st, 3rd, ..., 99th percentiles of the parent CDF. Readers interested in examples of how Latin hypercube sampling schemes may be applied in an actual benefit-cost analysis are referred to a study by Chapman.[34]

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[32] Harris, Carl M. 1984. *Issues in Sensitivity and Statistical Analysis of Large-Scale, Computer-Based Models.* NBS GCR 84-466. Gaithersburg, MD: National Bureau of Standards.

[33] A CDF is a function that shows on the vertical axis the probability of a value being less than or equal to the corresponding value on the horizontal axis.

[34] Chapman, Robert E. 1992. *Benefit-Cost Analysis for the Modernization and Associated Restructuring of the National Weather Service.* NISTIR 4867. Gaithersburg, MD: National Institute of Standards and Technology.

3. Description of Evaluation Methods

Several methods of economic evaluation are available to measure the economic performance of a research program, a new technology, a building, a building system, or like investment, over a specified time period. These methods include, but are not limited to, present value of net benefits, present value of net savings, benefit-to-cost ratio, savings-to-investment ratio, and the adjusted internal rate of return. These methods differ in the way in which they are calculated and, to some extent, in their applicability to particular types of investment decisions. The methods described in this section are based on ASTM standardized practices.[35] Readers interested in an excellent, in-depth survey covering these as well as other methods are referred to Ruegg and Marshall.[36]

3.1 Present Value of Net Benefits and Present Value of Net Savings

The present value of net benefits (PVNB) method is reliable, straightforward, and widely applicable for finding the economically efficient choice among alternatives (e.g., building systems). It measures the amount of net benefits from investing in a given alternative instead of investing in the foregone opportunity (e.g., some other alternative or maintenance of the *status quo*).

PVNB is computed by subtracting the time-adjusted costs of an investment from its time-adjusted benefits. If PVNB is positive, the investment is economic; if it is zero, the investment is as good as the next best investment opportunity; if it is negative, the investment is uneconomical. Emphasis is on economic efficiency because the method is appropriate for evaluating alternatives which compete on benefits, such as revenue or other advantages which are measured in dollars, in addition to costs.

The present value of net savings (PVNS) method is the PVNB method recast to fit the situation where there are no important benefits in terms of revenue or the like, but there are reductions in future costs (e.g., reductions in the cost of ownership to consumers).[37] By treating savings like revenue benefits, the PVNB method may be reformulated as the PVNS method.

The PVNB for a given alternative, $a*$, may be expressed as the difference between eq (2.6) and (2.9):[38]

---

[35] ASTM, *ASTM Standards on Building Economics.*

[36] Ruegg and Marshall, *Building Economics,* pp. 16-104.

[37] If there are any benefits, say in the form of revenues or other positive cash flows, then add them to the cost savings associated with the alternative under analysis.

[38] Some texts (e.g., Ruegg and Marshall, *Building Economics*) use a subscript or superscript notation, *a1:a2*, to denote differences between time-adjusted benefits and costs of one course of action, *a1*, relative to a mutually exclusive alternative course of action, *a2*. The superscript $a*$ notation used in Chapter 2 may be taken to denote a stand alone alternative, the difference between two mutually exclusive alternatives, or the difference between a given alternative and the *status quo*. Therefore, the two styles of notation are consistent. Except for cases where the life-cycle costs of two mutually exclusive alternatives are being compared, the latter notation is used throughout this report.

$$
\begin{aligned}
PVNB^{a^*} &= PVB^{a^*} - \overline{PVC^{a^*}} \\
&= \sum_{t=-t^{\alpha}}^{T} \left(B_t^{a^*} - \overline{C_t^{a^*}} \right) / (1+d)^t \\
&= \sum_{t=-t^{\alpha}}^{T} \left[\sum_{j=1}^{J^{a^*}} B_{jt}^{a^*} - \left(\sum_{k=1}^{K^{a^*}} I_{kt}^{a^*} + \sum_{m=1}^{M^{a^*}} C_{mt}^{a^*} \right) \right] / (1+d)^t
\end{aligned}
\qquad (3.1)
$$

If there are no important benefits in terms of revenue or the like, but there are reductions in future costs, then the savings from alternative a^* in year t may be designated as:

$$
S_t^{a^*} = B_t^{a^*} - C_t^{a^*} \qquad (3.2)
$$

Therefore, the PVNS for a given alternative, a^*, may, upon simplification, be expressed as the difference between eq (2.6) and (2.8) less eq (2.7):[39]

$$
\begin{aligned}
PVNS^{a^*} &= \sum_{t=-t^{\alpha}}^{T} \left(S_t^{a^*} - I_t^{a^*} \right) / (1+d)^t \\
&= \sum_{t=-t^{a^*}}^{T} \left[\left(\sum_{j=1}^{J^{a^*}} B_{jt}^{a^*} - \sum_{m=1}^{M^{a^*}} C_{mt}^{a^*} \right) - \sum_{k=1}^{K^{a^*}} I_{kt}^{a^*} \right] / (1+d)^t \\
&= \left(PVB^{a^*} - PVC^{a^*} \right) - PVI^{a^*}
\end{aligned}
\qquad (3.3)
$$

It is important to note that the mathematical formulation yielding PVNS is merely a rearrangement of the same terms which yielded PVNB. If the decision maker anticipates revenues from the investment, then use the PVNB measure. If the decision maker expects costs to be reduced, as would be the case for an investment in energy conservation measures (e.g., installing high-performance windows and wall and attic insulation to improve the thermal integrity of the building envelope, and sizing HVAC equipment accordingly), then use the PVNS measure.

The PVNS for a given alternative may also be derived through reference to life-cycle costs (LCC). In section 2.3, it was stated that the life-cycle costs for alternative a^*, LCC^{a^*}, was equivalent to eq (2.9), the present value of combined costs for alternative a^*.

[39]PVNS for a given alternative, a^*, may also be expressed as the difference between eq (2.10) and (2.7) (i.e., $PVNS^{a^*} = PVS^{a^*} - PVI^{a^*}$).

To derive PVNS from LCC, consider the special case where the project is construction related. In this case, Ruegg and Marshall[40] define the life-cycle costs of a building or building system as:

$$LCC = PVI + (PVOM + PVRR + PVEN - PVRV) \qquad (3.4)$$

where PVI = the present value of investment costs;

$PVOM$ = the present value of nonfuel operating and maintenance costs;

$PVRR$ = the present value of repair and replacement costs;

$PVEN$ = the present value of energy costs; and

$PVRV$ = the present value of the resale value (or scrap or salvage value) less any disposal costs of the building or building system.

To maintain consistency with section 2.1, the terms within parenthesis in eq (3.4) are equivalent to the present value of non-investment costs (i.e., eq (2.8)). Next, consider two mutually exclusive alternatives, *a1* and *a2*, and their associated life-cycle costs, LCC^{a1} and LCC^{a2}, respectively. Equation (3.5), which takes the difference between the life-cycle costs of the two mutually exclusive alternatives, yields the desired result:

$$PVNS^{a1:a2} = LCC^{a2} - LCC^{a1} \qquad (3.5)$$

where $PVNS^{a1:a2}$ = the present value of net savings attributed to a given alternative, *a1*, as compared with those of a mutually exclusive alternative, *a2*.

Equation (3.5) is therefore equivalent to eq (3.3). Readers interested in a comprehensive treatment of life-cycle costs for construction-related projects, including case examples and solution procedures, are referred to a report by Fuller and Petersen.[41]

3.2 Benefit-to-Cost Ratio and Savings-to-Investment Ratio

The benefit-to-cost ratio (BCR) and the savings-to-investment ratio (SIR) are numerical ratios whose size indicates the economic performance of an investment. The BCR is computed as benefits, net of future non-investment costs, divided by investment costs. The SIR is savings divided by investment costs. The SIR is the BCR method recast to fit the situation where the investment's primary advantage is lower costs. SIR is to BCR as PVNS is to PVNB.

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[40] Ruegg and Marshall, *Building Economics*, pp. 16-33.

[41] Fuller, Sieglinde K. and Stephen R. Petersen. 1996. *Life-Cycle Costing Manual for the Federal Energy Management Program.* NIST Handbook 135, Gaithersburg, MD: National Institute of Standards and Technology.

A ratio less than 1.0 indicates an uneconomic investment; a ratio of 1.0 indicates an investment whose benefits or savings just equal its costs; and a ratio greater than 1.0 indicates an economic project. A ratio of, say, 4.75 means that the investor (e.g., the general public for a public-sector research program) can expect to receive $4.75 for every $1.00 invested (e.g., public funds expended), over and above the required rate of return imposed by the discount rate.

The BCR for a given alternative, a^*, may be expressed as the difference between eq (2.6) and (2.8) divided by eq (2.7):

$$BCR^{a^*} = \left(PVB^{a^*} - PVC^{a^*} \right) / \, PVI^{a^*} = \frac{\sum_{t=-t^{\alpha}}^{T} \left(B_t^{a^*} - C_t^{a^*} \right) / \, (1+d)^t}{\sum_{t=-t^{\alpha}}^{T} I_t^{a^*} / \, (1+d)^t} = \frac{\sum_{t=-t^{\alpha}}^{T} \left(\sum_{j=1}^{J^{a^*}} B_{jt}^{a^*} - \sum_{m=1}^{M^{a^*}} C_{mt}^{a^*} \right) / \, (1+d)^t}{\sum_{t=-t^{\alpha}}^{T} \left(\sum_{k=1}^{K^{a^*}} I_{kt}^{a^*} \right) / \, (1+d)^t} \tag{3.6}$$

Since the difference between the terms within parentheses in the numerator of the BCR is equal to the savings for alternative a^* in year t, the SIR for alternative a^* may be expressed as:

$$SIR^{a^*} = \frac{\sum_{t=-t^{\alpha}}^{T} S_t^{a^*} / \, (1+d)^t}{\sum_{t=-t^{\alpha}}^{T} I_t^{a^*} / \, (1+d)^t} = PVS^{a^*} \, / \, PVI^{a^*} \tag{3.7}$$

As was the case for the PVNB and PVNS measures, use the BCR if the decision maker anticipates revenues from the investment, and use the SIR if the decision maker anticipates costs to be reduced.

3.3 Adjusted Internal Rate of Return

Before describing the adjusted internal rate of return (AIRR), it is instructive to review another concept, the internal rate of return (IRR). This approach is taken to enable the reader to distinguish between the two rate-of-return methods and to understand the advantages of the AIRR over the IRR.

The IRR is a measure of the percentage yield on an investment. The IRR is compared against the investor's minimum acceptable rate of return (MARR) to ascertain the economic attractiveness of the investment. The MARR is based on the opportunity cost of capital and is identical to the discount rate, *d*, discussed in section 2.3.1. If the IRR exceeds the MARR, the investment is economic. If it is less than the MARR, the investment is uneconomic. If the IRR equals the MARR, the investment's benefits (savings) just equal its costs, after taking into account the time value of money.

The IRR has two shortcomings which may limit its usefulness.[42] First, it may cause the decision maker to select the less profitable of two investment alternatives. Second, it may give either no measure or multiple measures of return, and thereby fail to provide clear direction for making decisions.

The AIRR is the annual yield from a project over the study period, taking into account reinvestment of interim receipts. Project earnings and earnings from reinvestment are accumulated to the end of the study period and set equal to the present value of cost to compute the AIRR. The AIRR was developed to provide a rate-of-return measure of economic performance without the limitations of the IRR. A growing number of practitioners are adopting the AIRR in place of the IRR.

Unlike the IRR, the AIRR produces a unique solution value and is easy to compute. The reinvestment rate is explicit. The AIRR provides a correct measure of performance over the study period provided the reinvestment rate is set correctly. Furthermore, the AIRR gives results consistent with PVNB (PVNS) in applications they share.[43]

The IRR for a given alternative, a^*, is computed by solving for the value of the discount rate, d^*, which will result in a value of PVNB (PVNS) equal to zero when used to discount benefits (savings) and costs. The solution discount rate, d^*, converted to a percent is the IRR. Find the minimum value of d^* for which:

$$PVNB^{a^*} = \sum_{t=-t^{\alpha}}^{T} \left(B_t^{a^*} - \overline{C_t^{a^*}} \right) / (1+d^*)^t = 0 \qquad (3.8)$$

where d^* = IRR expressed as a decimal.

Alternatively, if emphasis is on cost reductions, find the value of d^* for which:

---

[42] For a good treatment on the advantages and disadvantages of the IRR and AIRR, see, Marshall, Harold E. 1986. "Advantages of the Adjusted Rate of Return." *Cost Engineering* (February): pp. 32-7.

[43] A condition for obtaining results from the AIRR method consistent with results from the PVNB (PVNS) method is that the reinvestment rate be set equal to the discount rate.

$$PVNS^{a^*} = \sum_{t=-t^{\alpha}}^{T} \left(S_t^{a^*} - I_t^{a^*} \right) / (1+d^*)^t = 0 \tag{3.9}$$

Because the AIRR calculation explicitly includes the reinvestment of all net cash flows, it is instructive to introduce a new term, terminal value (TV). The terminal value of an investment, a^*, is the future value (i.e., the value at the end of the study period) of reinvested net cash flows excluding all investment costs. The terminal value for an investment a^*, is denoted as TV^{a^*}.

The reinvestment rate in the AIRR calculation is equal to the minimum attractive rate of return (MARR), the opportunity cost of capital, which is assumed to equal the discount rate, d, a constant. When the reinvestment rate is made explicit, all investment costs are easily expressible as a time equivalent initial outlay (i.e., a value at the beginning of the study period) and all non-investment cash flows (e.g., benefits, non-investment costs, savings) as a time equivalent terminal amount. This allows a straightforward comparison of the amount of money that comes out of the investment (i.e., the terminal value) with the amount of money put into the investment (i.e., the time equivalent initial outlay).

The AIRR is defined as the interest rate, r^*, applied to the terminal value, TV^{a^*}, which equates (i.e., discounts) it to the time equivalent value of the initial outlay of investment costs. It is important to note that all investment costs are discounted to a time equivalent initial outlay (i.e., to the beginning of the study period) using the discount rate, d.

Because the AIRR measures the annual yield from a project over the entire length of the study period, it is instructive to first derive the AIRR calculation for the simplest case, namely when the base year (i.e., t=0) is at the beginning of the study period. Next, the case where the base year is at the end of the study period will be derived. Finally, the case where the base year is in between the beginning and end of the study period will be derived. The descriptions given in sections 3.3.1 through 3.3.3 mirror the presentation given in section 2.3.2.2., where the three placements for the base year were described and illustrated graphically in figures 2-1, 2-2, and 2-3.

3.3.1 AIRR Calculation for Base Year at the Beginning of the Study Period

If the base year is at the beginning of the study period, then terminal value is defined as:

$$TV^{a^*} = \sum_{t=o}^{L} \left(B_t^{a^*} - C_t^{a^*} \right) (1+d)^{L-t} \tag{3.10}$$

where L = the length of the study period;

d = the prescribed rate of return on the reinvestment of net cash flows; and

$L-t$ = the number of time periods over which the net cash flows in year t are carried forward (i.e., compounded) at the specified reinvestment rate, d, to the end of the study period, L.

Since the base year occurs at the beginning of the study period, the time equivalent value of the initial outlay of investment costs is equal to the present value of investment costs, PVI^{a^*}. Therefore, for the case where the base year occurs at the beginning of the study period, the AIRR—expressed as a decimal—is that value of r^* for which:

$$\frac{TV^{a^*}}{(1+r^*)^L} = \sum_{t=o}^{L} I_t^{a^*} / (1+d)^t = PVI^{a^*} \tag{3.11}$$

where r^* = AIRR expressed as a decimal; and

L = the length of the study period.

Through simplification

$$(1+r^*)^L = \left(\frac{TV^{a^*}}{PVI^{a^*}} \right) \tag{3.12}$$

by taking the root of eq (3.12), the closed-form solution for r* is obtained:

$$r^* = \left(\frac{TV^{a^*}}{PVI^{a^*}} \right)^{\frac{1}{L}} - 1 \tag{3.13}$$

An additional relationship, that between the AIRR and the BCR (SIR), may now be derived by first noting that:

$$(1+d)^{L-t} = (1+d)^L / (1+d)^t \tag{3.14}$$

This implies that

$$TV^{a^*} = (1+d)^L \left[\sum_{t=o}^{L} \left(B_t^{a^*} - C_t^{a^*} \right) / (1+d)^t \right] \tag{3.15}$$

Therefore, substituting for TV^{a^*} in eq (3.12), combining terms and upon simplification:

$$\begin{aligned}(1+r^*)^L &= (1+d)^L \, BCR^{a^*} \\ &= (1+d)^L \, SIR^{a^*}\end{aligned} \tag{3.16}$$

by taking the root of eq (3.16), the closed-form solution for r* is once again obtained:

$$\begin{aligned}r^* &= (1+d)\;(BCR^{a^*})^{\frac{1}{L}} - 1 \\ &= (1+d)\;(SIR^{a^*})^{\frac{1}{L}} - 1\end{aligned} \tag{3.17}$$

3.3.2 AIRR Calculation for the Base Year at the End of the Study Period

If the base year is at the end of the study period, then terminal value is defined as:

$$\begin{aligned}TV^{a^*} &= \sum_{t=-L}^{0} (B_t^{a^*} - C_t^{a^*})\;(1+d)^{0-t} \\ &= \sum_{t=-L}^{0} (B_t^{a^*} - C_t^{a^*})\;(1+d)^{-t} \\ &= \sum_{t=-L}^{0} (B_t^{a^*} - C_t^{a^*})\;/\;(1+d)^{t}\end{aligned} \tag{3.18}$$

where $(1+d)^0$ = 1; and

L = the length of the study period.

The present value of investment cost, PVI^{a^*}, is defined as:

$$PVI^{a^*} = \sum_{t=-L}^{0} I_t^{a^*} \;/\; (1+d)^t \tag{3.19}$$

Because both TV^{a^*} and PVI^{a^*} are at the end of the study period, it is necessary to first bring both terms back to the beginning of the study period before equating them. This relationship is given by:

$$\frac{TV^{a^*}}{(1+r^*)^L} = \frac{PVI^{a^*}}{(1+d)^L} \tag{3.20}$$

Notice that the first part of eq (3.20) is merely the left-hand side of eq (3.11). This is because TV^{a*} is treated in the same way as in the case where the base year was at the beginning of the study period. Because TV^{a*} occurs at the end of the study period, it is brought back to the beginning of the study period using the interest rate, $r*$, and the single present value factor. The second part of eq (3.20) applies the discount rate, d, and the single present value factor to bring PVI^{a*} back to the beginning of the study period (i.e., to express it as a time equivalent initial outlay).

Rearranging terms and substituting for TV^{a*}, produces the following relationship:

$$(1+r*)^L = \frac{(1+d)^L \left[\sum_{t=-L}^{0} (B_t^{a^*} - C_t^{a^*}) \;/\; (1+d)^t \right]}{PVI^{a^*}} \tag{3.21}$$

Taking the root of eq (3.21), combining terms, and upon simplification, the closed-form solution for $r*$ is once again obtained:

$$\begin{aligned} r* &= (1+d)\ (BCR^{a^*})^{\frac{1}{L}} - 1 \\ &= (1+d)\ (SIR^{a^*})^{\frac{1}{L}} - 1 \end{aligned} \tag{3.22}$$

3.3.3 AIRR Calculation for the Base Year in Between the Beginning and the End of the Study Period

If the base year is in between the beginning and the end of the study period, then terminal value is defined as:

$$TV^{a^*} = \sum_{t=-t^{\alpha}}^{T} (B_t^{a^*} - C_t^{a^*}) \, (1+d)^{T-t}$$

$$= (1+d)^T \sum_{t=-t^{\alpha}}^{T} (B_t^{a^*} - C_t^{a^*}) \, / \, (1+d)^t \qquad (3.23)$$

where $t^{\alpha} + T = L$, the length of the study period.

The present value of investment cost, PVI^{a^*}, is defined as:

$$PVI^{a^*} = \sum_{t=-t^{\alpha}}^{T} I_t^{a^*} \, / \, (1+d)^t \qquad (3.24)$$

Because TV^{a^*} is at the end of the study period while PVI^{a^*} is in between $-t^{\alpha}$ and T, it is necessary to first bring both terms back to the beginning of the study period before equating them. This relationship is given by:

$$\frac{TV^{a^*}}{(1+r^*)^L} = \frac{PVI^{a^*}}{(1+d)^{t^{\alpha}}} \qquad (3.25)$$

Rearranging terms and substituting for TV^{a^*}, produces the following relationship:

$$(1+r^*)^L = \frac{(1+d)^{t^{\alpha}} \, (1+d)^T \left[\sum_{t=-t^{\alpha}}^{T} (B_t^{a^*} - C_t^{a^*}) \, / \, (1+d)^t \right]}{PVI^{a^*}} \qquad (3.26)$$

Through simplification, eq (3.26) becomes:

$$(1+r^*)^L = \frac{(1+d)^L \left[\sum_{t=-t^\alpha}^{T} (B_t^{a^*} - C_t^{a^*}) \; / \; (1+d)^t \right]}{PVI^{a^*}} \tag{3.27}$$

Taking the root of eq (3.27), combining terms, and upon simplification, the closed-form solution for r^* is once again obtained:

$$\begin{aligned} r^* &= (1+d) \; (BCR^{a^*})^{\frac{1}{L}} - 1 \\ &= (1+d) \; (SIR^{a^*})^{\frac{1}{L}} - 1 \end{aligned} \qquad 3.28$$

It is important to note that eqs (3.17), (3.22), and (3.28) all yield the same closed-form solution for r^*, the AIRR expressed as a decimal. What does this imply for the calculated value of r^*? Several key terms, namely L, the length of the study period, and d, the discount rate, are the same in eqs (3.17), (3.22), and (3.28). Consequently, the response to the question just posed hinges on the values of the benefit-to-cost ratio (BCR) and of the savings-to-investment ratio (SIR) which enter into eqs (3.17), (3.22), and (3.28). However, the values of the BCR and of the SIR are invariant to the choice of the base year (i.e., the choice of the year where t=0). For example, if the base year is at the beginning of the study period, it may be translated to the end of the study period by multiplying all costs (investment and non-investment), benefits, and savings by $(1+d)^L$ and the suitable value of a price index (e.g., the consumer price index) to adjust for real price changes. Since the BCR and the SIR are ratios, these multiplicative factors cancel. Therefore, the calculated values of the BCR and of the SIR remain the same. Consequently, the calculated value of r^* is also invariant to the choice of the base year. Equations (3.17), (3.22), and (3.28) are thus identical and will yield the same calculated value for r^*.

In general, the calculated values of the present value of net benefits (PVNB) and the present value of net savings (PVNS) ***are*** affected by the choice of the base year. Consequently, care should be exercised in selecting the base year for these economic evaluation methods.

Because the AIRR (1) incorporates reinvestment of net cash flows, (2) provides a unique solution which is easily calculated, and (3) relates to the BCR (SIR), use it in place of the IRR.

3.4 Summary of Methods[44]

The methods presented in the previous sections provide the basis for evaluating the economic performance of research investments. The equations underlying the methods presented earlier were all based on ASTM standardized methods. Although all of these methods can be used to evaluate accept or reject type decisions, there are several distinctions between the methods which are worth noting. These distinctions are important because they tie back to the decision maker's objective function.

There are four basis types of investment decisions for which an economic analysis is appropriate:

(1) whether to accept or reject a given project;

(2) the most efficient project size/level, system, or design;

(3) the optimal combination of interdependent projects (i.e., the right mix of sizes/levels, systems, and designs for a group of interdependent projects); and

(4) how to prioritize or rank independent projects when the allowable budget can not fund them all.

Each type of investment decision is important in a research environment. First, and foremost, decision makers need to know whether or not a particular project or program should be undertaken in the first place. Second, how should a particular research project/program be configured? The third type of decision builds on the second and introduces an important concept, interdependence. Many research projects/programs are multidisciplinary and are analogous to a portfolio. In addition, there may be both economies of scale (e.g., spreading out the use of specialized equipment) and of scope (e.g., packaging of staff talents). Consequently, for a given set of skills, laboratory facilities, candidate projects, and implied interdependencies, the problem becomes how to choose that combination of projects which maximizes PVNB (PVNS). The fourth type of decision introduces a budget constraint. The key here is how to get the most impact for the given budget amount.

In order to address the third and fourth types of decision, it is necessary to first develop a mathematical formulation of each decision problem.[45] For an optimum combination of interdependent projects, the goal is to maximize aggregate present value of net benefits:

$$Maximize \sum_{a=1}^{A} PVNB^{a} \times X^{a} \qquad (3.29)$$

[44]For a comprehensive treatment of how to choose among economic evaluation methods, see the NIST/BFRL video (Marshall, Harold E. 1995. *Choosing Economic Evaluation Methods—Part III in the Audiovisual Series on Least-Cost Energy Decisions for Buildings.* Gaithersburg, MD: NIST) and workbook (Marshall, Harold E. 1995. *Least-Cost Energy Decisions for Buildings—Part III: Choosing Economic Evaluation Methods Video Training Workbook.* NISTIR 5604. Gaithersburg, MD: NIST).

[45]Both formulations are given based on the aggregate present value of net benefits. Formulations based on the aggregate present value of net savings are identical except that present value of net savings is substituted for present value of net benefits.

where X^a = 1 if alternative a is chosen; and

0 otherwise.

For an optimum combination of independent projects whose selection is limited by a budget constraint, L, the goal is to maximize aggregate present value of net benefits:

$$\begin{aligned} &\textit{Maximize} \sum_{a=1}^{A} PVNB^a \times X^a \\ &\textit{Constrained by} \sum_{a=1}^{A} I^a \times X^a \leq L \end{aligned} \qquad (3.30)$$

where I^a = the initial investment cost for alternative a at the base time; and

L = the budget constraint.

Table 3-1 provides a summary of when it is appropriate to use each of the evaluation methods described earlier. Note that the PVNB (PVNS) method is appropriate in three of the four cases. Only in the presence of a budget constraint is the use of PVNB (PVNS) inappropriate and even in that case it plays an important role in computing the aggregate measure of performance.

Table 3-1. Summary of Appropriateness of Each Standardized Evaluation Method for Each Decision Type

Decision Type	PVNB PVNS	BCR SIR	AIRR
Accept/Reject	Yes	Yes	Yes
Design/Size	Yes	No	No
Combination (Interdependent)	Yes	No	No
Priority/Ranking (Independent)	No	Yes	Yes

Table 3-2 summarizes the accept/reject rule for each method. For each evaluation method, the computed value is based on an equation given in chapter 3. Acceptance implies that investment in the given project is economic. For PVNB and PVNS, eqs (3.1) and (3.3) provide the basis for the calculated value. For BCR and SIR, eqs (3.6) and (3.7) provide the basis for the computed value. For AIRR, eq (3.17) provides the basis for the computed value.

Table 3-2. Relationship of Accept/Reject Rule and Computed Value of Each Standardized Evaluation Method

Accept When	PVNB PVNS	BCR SIR	AIRR
Computed Value	>0	>1.0	>MARR

If the decision involves size/level, system, or design considerations, select the size/level, system, or design with the highest PVNB (PVNS). Do not use BCR (SIR) or AIRR for this type of decision.[46]

If the decision involves the optimal combination of interdependent projects, the rule is to select the combination that maximizes the sum of the PVNB (PVNS) for _all_ the candidate combinations (see eq (3.29)). Do not use BCR (SIR) or AIRR for this type of decision.[47]

The last type of decision is more complex. If there exists a set of projects, all of which can be accepted (i.e., PVNB (PVNS) > 0, BCR (SIR) >1.0, AIRR > MARR), but which exceed the allowable budget, the problem becomes how to allocate the budget so as to get the greatest value.[48] The decision is a two-step process. First, rank the projects in descending order of their BCRs (SIRs) or AIRRs. Second, select projects in descending order until the budget is exhausted. This selection procedure will ensure that aggregate PVNB (PVNS) for the limited budget is maximized. Due to the budget constraint, a straight application of the PVNB (PVNS) method is not appropriate.

The previous discussion points out the need for more than one evaluation method when conducting an economic impact study. Always report PVNB (PVNS) because it accounts for variation in benefits (savings) as well as costs among investment alternatives. In addition, depending on the decision maker's objective function, report either the BCR (SIR), a dimensionless number, or the AIRR, a percent rate of return.

To better understand the need for multiple measures, consider the case summarized in table 3-3. In this simplified example two proposed projects have the same estimated BCR, a value of 4.75. Although the 4.75 BCR is helpful to understand how much "relative" impact the projects have, it tells us little about "overall" or "absolute" impacts and nothing about the level of resource commitments.

Table 3-3 summarizes the present value of investment costs (see column (1)), of benefits (see column (2)), and of net benefits (see column (3)). Non-investment costs for both projects are assumed to be zero. Values for the BCR and for a subsequent AIRR calculation are also given in table 3-3.

[46] If the incremental BCR (SIR) or AIRR for each size/level, system, or design is computed, then their use may be appropriate; see Marshall, *Choosing Economic Evaluation Methods,* pp. 17-22.

[47] If the incremental BCR (SIR) or AIRR is computed for each combination, then their use may be appropriate; see Ruegg and Marshall, *Building Economics,* pp. 54-64.

[48] The greatest value is defined as that combination which maximizes PVNB (PVNS) without exceeding the budget limitation (see eq(3.30)).

Table 3-3. Case Example Illustrating the Need for Multiple Measures

Project	BCR	Present Value			AIRR (4)
		Investment (Costs) (1)	Benefits (2)	Net Benefits (3)	
a1	4.75	$100,000	$475,000	$375,000	28.5%
a2	4.75	$1,000,000	$4,750,000	$3,750,000	28.5%

Through reference to table 3-3, we see that the present value of investment costs (see column (1) of the table) for project a1, PVI^{a1}, is $100,000 and the present value of benefits (see column (2) of the table) for project *a1*, PVB^{a2}, is $475,000 (i.e., $100,000 x 4.75). The present value of investment costs for project *a2*, PVI^{a2}, is $1,000,000 and the present value of benefits, PVB^{a2}, is $4,750,000.

The present value of net benefits for each project is shown in column (3) of table 3-3. Reference to column (3) reveals that the net benefits of the larger project, $PVNB^{a2}$, exceed those of the smaller project by a factor of 10—in absolute terms by $3,375,000.

The same type of outcome would occur if the AIRR were used. Again to keep the example simple, consider the case given in table 3-3. If the length of the study period and the reinvestment rate were the same for both projects, then they would result in the same value of the AIRR (see eq (3.17)). The entries in column (4) of table 3-3 assume a reinvestment rate of 10 percent and a 10-year study period. The resultant AIRR is 28.5 percent per year for each project over the 10-year study period.

The previous example demonstrates that only the PVNB (PVNS) method captures variations in the present values of benefits (savings) and investments. Furthermore, the information required to compute the value of PVNB (PVNS) is the same as is required to compute the value of the BCR (SIR) and of the AIRR. Thus, requiring that the value of PVNB (PVNS) be computed to show the absolute impacts of the proposed research investment alternatives, does not in any way preclude the use of other measures.

In summary, there are several reasons why multiple measures are necessary. First and foremost, managers want to know if a particular research project is economic. Reference to table 3-2 shows that all of the evaluation methods address this type of decision. Furthermore, these evaluation methods may be used *ex ante* for emerging technologies as well as *ex post* for past research projects. Second, as issues of design, sizing, and packaging combinations of projects become the focus of attention—as often occurs in conjunction with budget reviews—the PVNB (PVNS) method emerges as the principle means for evaluating a project's or program's merits. Finally, the tightening budget picture involves setting priorities. Multiple measures, when used appropriately, ensure consistency in both setting priorities and selecting projects for funding. The two case studies presented in chapters 5 and 6 illustrate the importance of multiple evaluation methods.

4. Presentation and Analysis of Results: A Suggested Approach

The presentation and analysis of the results of an economic impact study are central to understanding and accepting its findings. If the presentation is clear and concise and if the analysis strategy is logical, complete, and carefully spelled out, then the results should stand up under close scrutiny. The purpose of this section is to outline a generic format to employ for economic impact studies in general and which meets the two previously-cited conditions. The generic format is built upon the following three factors: (1) the significance of the research effort; (2) the analysis strategy; and (3) the calculation of key benefit and cost measures. A specific format, tailored to BFRL, is given in exhibit 4-1; it is used as the basis for summarizing the two case study applications given in chapters 5 and 6.

The three factors for the generic format referenced above are now related to the specific format given in exhibit 4-1. Exhibit 4-1 is divided into two columns. The first column contains three entries 1.a, 2, and 3.a. These entries correspond to the three factors referenced in the previous paragraph. Their purpose is to provide sufficient information to understand the basics of the research effort under analysis. The second column contains two entries 1.b and 3.b. These entries highlight the **key** observations from entries 1.a and 3.a, respectively. These key observations may be thought of as talking points for summarizing the research effort under analysis. Exposition of the generic format serves two purposes. First, it provides a means for organizing an in-depth economic impact study for presentation. Second, it provides a vehicle for clearly and concisely presenting the salient results of an economic impact study to senior research managers (e.g., laboratory directors). Such summaries for the two BFRL case studies are provided at the beginning of chapters 5 and 6, respectively.

4.1 Significance of Research Effort

This section of an economic impact study sets the stage for the results which follow. The goal at this point is to clearly describe:

(1) why the research is important and how the organization conducting the research became involved; and

(2) why some or all of the changes brought about were due to the research organization's contribution.

Emphasis is placed on providing dollar estimates to define the magnitude of the problem. If any non-financial characteristics are of key importance to senior management, they should be listed and described briefly. A clear tie into the research organization's mission or vision is included to demonstrate why the organization conducting the research is well qualified and well positioned to participate in the research effort. The section concludes with a statement of the research organization's contribution.

Exhibit 4-1. Format for Summarizing the Economic Impacts of BFRL Research Efforts

a Significance of Research Effort:

escribe why the research is important and how BFRL became volved.

escribe the changes brought about by the BFRL research effort.

1.b Key Points:

Highlight two or three key points which convey why this research effort is important.

Analysis Strategy:

escribe how the present value of **total benefits (savings)** to the nation stemming from all contributors to the search effort was determined.

escribe how the present value of **total costs** to the nation stemming from all contributors to the research effort as determined

escribe how the present value **net benefits (savings)** to the nation was determined.

escribe how the present value of **total benefits (savings)** attributable to BFRL's research effort was determined.

escribe how the present value of **total costs** attributable to BFRL's research effort was determined.

escribe how the present value of **net benefits (savings)** attributable to BFRL's research effort was determined.

escribe how any **additional measures** were calculated and how BFRL's contribution was determined.

ımmarize key data and assumptions: (a) Base year; (b) Length of study period; (c) Discount rate or minimum ceptable rate of return; (d) Data; and (e) Other.

a Calculation of Benefits, Costs, and Additional easures:

otal Benefits (Savings):
eport the present value of the total benefits (savings) attributable to FRL's research effort.

otal Costs:
eport the present value of the total costs attributable to BFRL's search effort.

et Benefits (Savings):
eport the present value of net benefits (savings) attributable to FRL's research effort.

dditional Measures:
eport the values of any additional measures calculated.

3.b Key Measures:

Report the calculated value of the Present Value of Net Benefits (PVNB) ***or the Present Value of Net Savings*** *(PVNS)* attributable to BFRL **and** at least one of the following:

* Benefit-to-Cost Ratio (BCR) *or Savings-to-Investment Ratio (SIR)*
* Adjusted Internal Rate of Return (AIRR)

4.2 Analysis Strategy

This section of an economic impact study focuses on documenting the steps taken to ensure that the analysis strategy was logical and complete. Particular emphasis is placed on summarizing the key data and assumptions, including any constraints which limited the scope of the study. Responses are provided for key data and assumptions concerning: (a) the base year for the study; (b) the length of the study period; and (c) the discount rate or minimum acceptable rate of return used.

Special emphasis is placed on documenting the *sources and validity* of any data used to make estimates or projections of key benefit and cost measures. This section establishes an audit trail from the raw data, through data manipulations (e.g., represented by equations and formulae), to the results which describe:

(1) the present value of **total benefits (savings)** to the nation stemming from all contributors to the research effort under study;

(2) the present value of **total costs** for all contributors to the research effort under study, any users of the new technology under study, and any third parties affected by either the research effort or the use of the new technology;

(3) the present value of **net benefits (savings)** to the nation stemming from all contributors to the research effort under study, any users of the new technology under study, and any third parties affected by either the research effort or the use of the new technology;

(4) the present value of **total benefits (savings)** attributable to the research organization's contribution;

(5) the present value of **total costs** attributable to the research organization's contribution;

(6) the present value of **net benefits (savings)** attributable to the research organization's contribution; and

(7) any **additional measures** that were calculated.

4.3 Calculation of Benefits, Costs, and Additional Measures

This section of an economic impact study focuses on reporting the calculated values of the key benefit and cost measures, as well as any additional measures which are deemed appropriate. Because the material in chapter 3 provides information on these key measures, including when it is appropriate to use each of the measures for choosing among research investments, no discussion of the pros and cons of any of the measures will be given here. At this point, we note that it is essential to report the calculated value of the present value of net benefits *or the present value of net savings* attributable to the research organization's contribution and at least one of the following:

(a) the benefit-to-cost ratio *or the savings-to-investment ratio*; or

(b) the adjusted internal rate of return.

Summaries of the following information are also reported:

(1) the present value of the total benefits (savings) attributable to the research organization's contribution;

(2) the present value of the total costs attributable to the research organization's contribution;

(3) the present value of net benefits (savings) attributable to the research organization's contribution; and

(4) the values of any additional measures calculated.

5. ASHRAE 90-75 Case Study

5.1 Residential Energy Conservation

Energy consumption in buildings—which accounts for 20 percent of total U.S. energy consumption—was identified as a major conservation target in the late 1960's. Because of an increasing number of brownouts in various regions of the U.S., many states were well on their way to developing energy conservation standards even before the 1973 oil embargo. To ensure consistency among those standards, the National Conference of States on Building Codes and Standards (NCSBCS) requested NIST's Building and Fire Research Laboratory (BFRL, then the NBS Center for Building Technology) in 1973 to develop recommendations for building code provisions for energy conservation. NIST was further directed by the Energy Policy and Conservation Act of 1975 to develop test procedures for evaluating the energy efficiency of residential energy-consuming equipment. The results of the BFRL development work were issued as a technical report in February 1974 and revised and reissued in February 1976;[49] they provided the technical basis for ASHRAE Standard 90-75, *Energy Conservation in New Building Design.* ASHRAE Standard 90-75 was issued in August of 1975.

To lay the foundation for an evaluation of ASHRAE 90-75, the Department of Energy (DOE) (then the Federal Energy Administration) retained Arthur D. Little, Inc. (ADL) in 1975 to investigate the potential energy and economic impact the standard would have. The ADL study[50] investigated, for a variety of buildings and major geographical areas, the potential effect of the standard on building energy consumption, and also on initial (capital) and operating costs of new buildings, building habitability, the nation's annual energy requirements in construction, and the potential economic impact on selected sectors within the construction industry. To estimate the impact of ASHRAE 90-75, ADL performed two sets of calculations for prototype residential and non-residential buildings; one without the standard and one with the standard in its strictest interpretation (i.e., all measures "required" rather than "recommended"). With respect to energy consumption in buildings, ADL estimated annual cost savings in residential and non-residential buildings per square foot for the year 1975.

The present study focuses on BFRL's contribution to energy conservation in single-family residences due to ASHRAE 90-75. Using as a point of departure the per square foot energy cost savings calculated by ADL for an ASHRAE 90-75-modified prototype, we estimate the energy cost savings in new single-family houses constructed according to the standard in the U.S. from 1975 to 1984. Of particular interest is the share of savings that can be attributed to BFRL's participation in the development of ASHRAE 90-75. The analysis estimates that for the time period from 1975 to 1984 BFRL's contribution to the energy cost savings in single-family houses due to ASHRAE 90-75 was $919 million in 1975 present-value dollars. Expressed in 1995 dollars, this estimate amounts to $2.6 billion. Exhibit 5.1 provides an extended summary of the background, approach, and results of the study. Exhibit 5.1 utilizes the framework introduced in chapter 4 (see exhibit 4.1).

[49] National Bureau of Standards (NBS). 1974 (Revised 1976). *Design and Evaluation Criteria for Energy Conservation in New Buildings.* NBSIR 74-452. Gaithersburg, MD: National Bureau of Standards.

[50] *Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75,* Conservation Paper 43B, prepared for the Federal Energy Administration by Arthur D. Little, Inc., 1975.

Exhibit 5-1. Summary of Economic Impacts of BFRL Research on ASHRAE 90-75

1.a Significance of Research Effort:

Energy consumption in buildings, which accounts for 20% of total U.S. energy consumption, was a major conservation target and the subject of NIST research even before the 1973 oil embargo. In early 1973, the National Conference of States on Building Codes and Standards (NCSBCS) asked BFRL to develop recommendations for building code provisions for energy conservation. NCSBCS's goal was to produce building code provisions that would be acceptable to industry in general and lead to consistent standards for all states. BFRL was further directed by the Energy Policy and Conservation Act of 1975 to develop test procedures for evaluating the energy efficiency of residential equipment.

The results of BFRL research were adopted as industry consensus standards by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) and most U.S. manufacturers for major appliances.

The standard was expected to have various beneficial energy and economic impacts. The expected energy savings in typical residences were estimated *ex ante* in a DOE-commissioned study *Energy Conservation in New Building Design: An Impact Assessment of ASHRAE 90-75,* conducted by Arthur D. Little, Inc. (ADL) in 1975. The portion of such nationwide impacts, as it relates to energy cost savings in single-family residences and is attributable to BFRL's research and development work, is the subject of this analysis.

1.b Key Points:

- Because of its past extensive and non-partisan research in building-related energy use and conservation, BFRL was asked by NCSBCS to develop recommendations for building code provisions for energy conservation.

- BFRL's participation led to the issuance in 1975 of ASHRAE Standard 90-75, which is now the basis for energy conservation building code requirements in most of the 50 states.

- A portion of the nationwide economic impacts of the standard can be attributed to BFRL's research and development work.

2. Analysis Strategy:

The objective of this study is to (1) evaluate *ex post,* for the period 1975 through 1994, the impact of ASHRAE 90-75 on energy costs in new single-family residences in the U.S., and (2) estimate BFRL's contribution to cost savings. The approach is to estimate in 1975 present value (PV) dollars, by major geographical area:

(1) **Total Potential PV Savings (PPVS)** in energy costs that could have been achieved in single-family residences constructed in the U.S. from 1975 to 1984 if ASHRAE 90-75 had been adopted and fully implemented for residential buildings by all states in 1975. The potential present value of savings for each year over the period of construction (i.e., 1975-1984) for which cost savings are measured is designated as $PPVS_y$.

(2) **PV Savings (PVS) attributable to BFRL** by estimating that portion of total potential savings that would have been foregone if, without BFRL's participation, the issuance and implementation of the standard had been delayed by four years. BFRL's contribution is calculated by applying to $PPVS_y$ the difference in each year between the actual adoption level and an assumed, delayed adoption level.

(3) **PV Net Savings (PVNS) for the BFRL contribution** by subtracting from total BFRL PVS the PV research and development costs (PV costs) incurred by BFRL.

(4) **Savings-to-Investment Ratio (SIR)** for the BFRL contribution by taking the ratio of total savings attributable to BFRL and the total costs incurred by BFRL. A ratio >1 indicates an economically worthwhile project.

(5) **Adjusted Internal Rate of Return (AIRR)**, the annual return on investment over the study period for the BFRL contribution. An AIRR > the discount rate indicates that the project is economically worthwhile.

Data and Assumptions:

- The period of construction for which costs and cost savings are measured begins in 1975 and ends in 1984; cost savings are assumed to accrue for 10 years beyond the year of construction, and R&D costs accrued during 1973-75. Hence the length of the study period is 22 years from 1973 to 1994.
- The base year is 1975 and all amounts are calculated in PV 1975 dollars.
- The base-year annual cost savings per unit area for ASHRAE-90-75-modified single-family residences for each major geographical area are taken from the 1975 ADL analysis.
- The discount rate is 10 percent (real), which is the OMB discount rate in effect for government projects in 1975.
- Only data on construction of single-family residences in states that adopted ASHRAE-90-75-based residential codes are included in the cost-savings calculations.
- The actual adoption rate for ASHRAE 90-75 is derived from information obtained from NCSBCS, Pacific Northwest Labs, and ASHRAE; the delayed adoption rate is derived by assuming that without BFRL's research, the adoption of the standard would have occurred four years later.
- The Consumer Price Index (CPI) for fuels (1982-84 = 100) is used to convert energy cost savings to 1995 dollars, and the CPI for all items (1982-84=100) to convert research and development costs.

3.a Calculation of Savings, Costs, and Additional Measures

- Savings and Costs:

Total Potential PV Cost Savings:
PPVS for each region and summed for U.S.
= Sum from 1975 to 1984 of $PPVS_y$ = \$5.52 billion,
where $PPVS_y$ = Annual savings/m^2 * no. of m^2 * UPV_{10}* SPV_{75} in year y.

Total Savings Attributable to BFRL:
PVS attributable to BFRL for each region and summed for U.S.
= Sum from 1975-1984 of ($PPVS_y$ * difference between actual and assumed, delayed adoption levels in year y) = \$919.4 million

PV Investment Costs to BFRL
= \$0.367 million

PV Net Savings attributable to BFRL:
PVNS = Difference between total savings attributable to BFRL and cost of BFRL research and development work
= \$919.4 - \$0.367 = \$919.0 million

- Additional Measures:

SIR of BFRL Contribution:
Savings-to-Investment Ratio = \$919.4 / \$0.367 = 2505

AIRR of BFRL Contribution:
Adjusted Internal Rate of Return on BFRL investment
$= (1 + 0.10) * 2505^{1/22} - 1$ = 0.57

3.b Key Results:

Savings Attributable to BFRL:

	1975-\$	1995-\$
	(\$ amounts in millions)	
PVS	\$919.4	\$2,602
PV Costs	\$0.367	\$1.039
PVNS	\$ 919.0	\$2,601
SIR	2505	
AIRR	57%	

5.2 Approach

5.2.1 Methodology

The basic approach used is to calculate first the total energy cost savings that could have been achieved from 1975 to 1984 if ASHRAE 90-75 had been adopted and implemented in residential buildings by all states upon its issuance in 1975. BFRL's contribution is then calculated by multiplying this estimate of total potential energy cost savings by the difference between the actual adoption rate and an assumed delayed adoption rate that would have prevailed if BFRL had not been involved in developing the test procedures and guidelines for the standard. The resulting amount measures the difference between the actual energy savings achieved with BFRL's involvement and the (smaller) savings that would have been attainable without BFRL's involvement.

To convert all amounts to 1975 present values, we use a real discount rate of 10 percent, which is the OMB discount rate in effect in 1975 for projects that benefit the public. The calculations combine the base-year (1975) energy cost savings per square foot derived by ADL with data on new residential construction in each of the four major geographical areas in each year from 1975 to 1984. We assume that the cost savings of an ASHRAE 90-75-modified house would continue to accrue over a period of 10 years from the date of construction. For example, for the houses built in 1984, the last year of the study period, the present value of energy savings includes the savings accumulated from 1984 to 1994. We assumed that savings attributable to ASHRAE 90-75 would benefit the occupant for at least 10 years beyond the construction of the house until major repairs or replacements would alter the original configuration and quality of energy-conserving systems.

Because the analysis is done *ex post*, the calculations in this study, conducted in 1995, use the **actual** adoption rates for ASHRAE 90-75 and data on **actual** construction of single-family houses for each of the years of the study period instead of the **projected** rates that were used in the ADL study. Since the rates of adoption and the number of newly constructed houses are different for each major geographical area in the U.S., the total estimate is arrived at by first calculating the corresponding energy cost savings for each geographical area separately and then summing the amounts across areas.

We also calculate the Present Value Net Savings (PVNS), Savings-to-Investment Ratio (SIR), and Adjusted Internal Rate of Return (AIRR) for BFRL's contribution to energy cost savings. How these evaluation methods are computed and interpreted is described in chapters 2 through 4.

5.2.2 Data and Assumptions

5.2.2.1 Length of Study Period

The study period was chosen to cover the years from 1973 to 1994. This period includes

- the time from 1973 to 1975 during which BFRL developed the relevant test procedures and specifications for ASHRAE 90-75;

- the interval between the issuance of ASHRAE 90-75 and its first major revision in 1980, plus an extension of four years to 1984 by which its issuance in 1975 and its rate of adoption would have been delayed if BFRL had not been involved in the development of the standard;[51]
- a period of ten years from the year of construction (the last year being 1984) over which the cost savings of an ASHRAE-modified house continue to accrue.

5.2.2.2 Base-Year Energy Cost Savings

The base-year energy cost savings per square foot (0.093 m^2) in single-family residences calculated by ADL for 1975 were based on climatic variations between the major geographical areas of the U.S., a set of prototype buildings to represent new residential construction, and an application of the standard to the prototypes. To arrive at the cost differences, ADL compared a 1975 prototype of a conventional single-family residence with one that met the ASHRAE 90-75 standard. There were three different prototypes, each adapted to the major geographical areas in the U.S. (i.e., one prototype for the Northeast and Midwest, and one each for the South and the West).

It was not necessary to include in this analysis increases in initial building costs incurred by the application of ASHRAE 90-75 because the ADL study had determined that any initial cost increases for exterior walls, glass, roofing, etc., were offset by the cost reductions made possible by HVAC systems of a smaller required size (see chapter IV, section C of the ADL study).

The assumptions of the ADL report regarding the calculation of the base-year energy cost savings and the steps in calculating the unit cost savings are briefly described in the remainder of this subsection.

Selection of geographical areas:
Since space heating is the overriding factor in energy demand for buildings, the variation in space heating requirements was the prime criterion for selecting geographical locations. To determine the representative energy usage for each of the major geographical areas in the U.S., the ADL study used averages of heating degree days and cooling loads, weighted by the number of housing units in each state and region.[52] Once the weighted average degree day and cooling load were calculated, a city with an annual heating and cooling degree load close to the regional average was selected for each region for simulating the energy usage of the conventional and ASHRAE 90-75-modified prototypes.

Selection of the prototypical residential building:
For the analysis of energy consumption in single-family residences, the ADL designed three prototype single-story, ranch-style residences with sloped roofs. The designs varied with respect to exterior wall construction, floor area, and configuration and had the following characteristics:

- Exteriors were either of lapped wood siding, brick, or stucco, depending on geographical location;
- sizes ranged from 149 to 158 m^2 (1600 to 1700 sq. ft.) in area;

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[51] 1980 was also the year of an NCSBCS survey that provided the information on the actual adoption rate at that time.

[52] A heating degree day is the Celsius (Fahrenheit) degrees difference in temperature between the (lower) mean temperature for the day and 18.3°C (65° F). Heating degree days are summed over the year to estimate annual fuel consumption and heating load of a building in winter. Cooling load is the amount of sensible and latent heat that must be removed by an air-conditioner per unit time.

- the amount of insulation was based on discussions with developers and homebuilders and was roughly equal to a thermal resistivity of 1.2 K · m^2/W (Standard R-7) or 1.9 K · m^2 (Standard R-11),
- window area was assumed to be 15 percent for all walls;
- roofs were sloped and covered with asphalt shingles.

The smaller-sized frame prototype was selected for the Northeast and Midwest regions, the larger-sized brick and stucco prototypes for the South and West regions respectively.

***Application of ASHRAE 90-75 to prototypical single-family residences*:**
A Philadelphia-based A/E design firm, Kling-Lindquist, Inc., developed and implemented the approach to modifying the prototypical residences in accordance with ASHRAE 90-75. The standard was applied in its strictest interpretation following a prescriptive/performance approach rather than a systems analysis approach.[53] The goal of the modification was to meet the standard but not to exceed it. The ASHRAE modifications applied to the exterior envelope, lighting/power, ventilation, infiltration, and domestic hot water. The usage of the predominant fuel types in each geographical area determined the quantity of energy consumed, and the same fuel types and hot water demand and temperature rise/drop were assumed in the conventional and the ASHRAE-modified buildings.

The effect of ASHRAE 90-75 on energy usage in single-family residences was to reduce consumption by 11.3 percent on average. For the individual regions the reductions in consumption are shown in table 5-1.

Since annual energy savings are for the most part due to savings in space heating, they are greater in the Northeast and Midwest where space heating accounts for 75 to 78 percent of total energy consumption. The next highest energy requirement is for hot water and is lower in the South and West where the incoming water is warmer than in the Northeast and Midwest. Reductions due to lighting and power are negligible; the ADL study assumed that single-family residences required the same amount of energy for lighting and power before and after the modification and regardless of the region.

[53] A prescriptive/performance approach selects building materials and systems based on well-defined performance criteria established through an element-by-element design analysis. Alternatively, a systems analysis approach allows for compliance if the building's energy consumption is shown to be equal to or lower than that achievable through the standard prescriptive/performance approach.

Table 5-1. Annual Energy Consumption in Single-Family Residences, 1975

Part A: Annual Consumption in Single-Family Residences

Region	Conventional		ASHRAE 90-75	
	GJ/m²	1000 Btu/ft²	GJ/m²	1000 Btu/ft²
Northeast	2.01	177.0	1.71	150.9
Midwest	2.22	195.8	1.89	166.5
South	0.85	75.2	0.79	69.4
West	1.14	100.4	1.05	92.9

Part B: Energy Reduction from ASHRAE 90-75

Region	GJ/m²	1000 Btu/ft²	Percent
Northeast	0.30	26.1	14.7
Midwest	0.33	29.3	15.1
South	0.07	5.8	7.7
West	0.09	7.5	7.5

Estimated annual energy cost savings:
ADL estimated annual operating costs both for the conventional and the ASHRAE 90-75-modified single-family residences, combining the regional energy consumption data with cost data as of June 1975. For each region, the average cost per square meter (per square foot) was determined by a weighted average technique based on the costs of electricity, gas, and oil in each region, and the population of the appropriate State Economic Areas (SEAs).[54] The unit costs are for the amount of fuel required to meet a minimum benchmark level for space heating in each SEA. The energy cost differences between the two prototypes therefore represent the 1975 unit values of annual energy saved in each region in going from a conventional to an ASHRAE 90-75-modified building. These figures, which are summarized in table 5-2, are used as the annual base-year cost savings in the methodology of the 1995 study.

[54]SEAs (State Economic Areas) of the Bureau of the Census are made up of two or more counties grouped together into substate regions.

Table 5-2. Base-Year Energy Cost Savings by Region

Region	Base-Year Energy Cost Savings	
	per m^2	per ft^2
Northeast	$1.464	$0.136
Midwest	$0.517	$0.048
South	$0.527	$0.049
West	$0.657	$0.061

To adjust the base-year savings for the energy price increases that occurred in each of the years of the study period, they are multiplied by the cumulative real changes in energy prices,[55] as listed in table 5-3, column (3). For example, the base-year energy cost savings per m^2 of $1.46 ($0.136/ft^2) in the Northeast increases by 4.9 percent to $1.53 ($0.143/ft^2) at the end of 1975, and by 8.1 percent to $1.58 ($0.147/ft^2) by the end of 1976, and so on through the end of the study period.

5.2.2.3 Construction Data

In order to calculate the energy savings in single-family houses attributable to ASHRAE 90-75, we used data on the number of privately owned one-family houses completed in each year from 1975 to 1984 in each geographical area, as published in *Current Construction Report, Characteristics of New Housing, C25 Series,* U.S. Bureau of the Census. Since the base-year energy cost savings were in dollars per square foot, we converted the number of houses completed to square foot area by using the appropriate datafrom the Construction Statistics Division of the U.S. Bureau of the Census. The square foot area was converted to square meters. Table 5-4 shows for each geographical region the number of one-family houses completed in each year of the study period and the corresponding area in square feet and square meters.

5.2.2.4 Adoption Rate of ASHRAE 90-75

The rate at which ASHRAE 90-75 was adopted and implemented by the individual states is a crucial part of the benefit calculation because it indicates what percentage of new buildings in the U.S. and, in our case,

[55]The real change in energy prices is calculated for each year of the study period as the difference between the CPI for all items and the CPI for fuels, that is, eliminating the rate of *general* inflation from the rate of change for energy prices leaves the *real* rate of change for energy prices.

Table 5-3. Real Change in Fuel Prices and Resulting UPV* Factors, 1975-1984

Year (1)	Annual Real Change in Fuel Prices e_i (2)	Cumulative Real Change in Fuel Prices $\prod_{i=1}^{t}(1+e_i)$ (3)	UPV_{10}* Factors based on real fuel price changes (4)
75	0.049	1.049	6.157
76	0.030	1.081	6.155
77	0.063	1.149	6.155
78	0.006	1.156	6.152
79	0.040	1.201	6.152
80	0.075	1.291	6.150
81	0.057	1.365	6.145
82	0.032	1.409	6.141
83	-0.001	1.407	6.137
84	-0.008	1.397	6.135
85	-0.030		
86	-0.069		
87	-0.053		
88	-0.033		
89	-0.017		
90	-0.017		
91	-0.020		
92	-0.017		
93	-0.001		
94	-0.021		

Table 5-4. New Single-Family Houses Completed and Corresponding Floor Area, 1975-1984

Part A: Northeast and Midwest

Year	Northeast			Midwest		
	Units (in 1,000)	Floor Area		Units (in 1,000)	Floor Area	
		Total m^2 (in 1,000)	Total ft^2 (in 1,000)		Total m^2 (in 1,000)	Total ft^2 (in 1,000)
75	114	16,681	179,550	218	32,000	344,440
76	121	18,323	197,230	271	41,667	488,505
77	135	20,694	222,750	300	45,987	495,000
78	141	22,662	243,930	300	48,217	519,000
79	135	22,513	242,325	294	46,979	505,680
80	100	16,444	177,000	170	26,612	286,450
81	87	14,589	157,035	140	21,721	233,800
82	79	12,881	138,645	92	14,145	152,260
83	106	17,677	190,270	142	22,889	246,370
84	129	22,291	239,940	156	26,087	280,800

Part B: South and West

Year	South			West		
	Units (in 1,000)	Floor Area		Units (in 1,000)	Floor Area	
		Total m^2 (in 1,000)	Total ft^2 (in 1,000)		Total m^2 (in 1,000)	Total ft^2 (in 1,000)
75	362	57,341	617,210	182	27,385	297,570
76	410	66,848	719,550	232	35,976	390,920
77	512	84,192	906,240	311	49,515	538,030
78	571	94,690	1,019,235	357	57,167	621,180
79	535	89,217	960,325	337	53,654	583,010
80	455	73,974	796,250	233	37,204	404,255
81	408	65,006	699,720	183	29,220	317,505
82	340	53,698	578,000	121	19,376	210,540
83	476	76,062	818,720	200	31,198	339,000
84	508	82,591	889,000	233	38,276	415,905

of new single-family residences, were built according to the ASHRAE 90-75 in each year of the study period. The calculation of BFRL's contribution to energy cost savings in single-family residences is based on the difference between the actual adoption rate of ASHRAE 90-75 and the adoption rate that would have existed if this or some other, equivalent, standard had been issued four years later. The justification for the four-year delay is that in the absence of a BFRL-promoted consensus standard, it would have taken at least four more years to distill and legislate some equivalent, commonly acceptable body of codes from the energy conservation attempts that were in progress in many of the U.S. states in the early 1970's.[56]

In deriving the adoption rate for each region, "ASHRAE 90-75-modified construction" is taken to mean construction in the states that adopted ASHRAE 90-75 itself or any energy codes modeled after it, such as the *Model Energy Code (MEC)* published by the Council of American Building Officials (CABO), or codes that include MEC as appendices. Excluded is the construction in the states whose codes are not based on ASHRAE 90-75 but instead, for example, on state-developed codes or on the *National Building Code*. This is to isolate the energy cost savings attributable to ASHRAE 90-75, the standard that directly resulted from BFRL's development work.

It was difficult to estimate an adoption rate for single-family residences from the information obtained from various sources. This is not surprising considering the complexity of the issue. There is a wide range of methods that are used by state, county, and city governments to adopt building energy codes. Some government units adopted ASHRAE 90-75 or model codes patterned after it, others developed their own codes, sometimes partially based on ASHRAE 90-75 or its derivatives. In some states there are codes for both residential and commercial buildings, for either one or the other, or only for public buildings or only for certain cities; they may have either mandated or voluntary codes, and in different stages of adoption. In addition, there is very little information available, for the years of the study period, on the degree of implementation of ASHRAE 90-75 in the states that adopted it.[57] Since the level of compliance in the 1970's is considered to have been rather high because of the 1973 oil crisis, it can be expected that there was a high degree of implementation in the states that adopted the standard for residential buildings.

In order to extract an operational adoption rate from the available data, we made the following simplifying assumptions:

(1) To isolate the effect of ASHRAE 90-75 on energy cost savings in single-family residences, we exclude those 16 states that, according to information from Battelle PNL[58] and an NCSBCS survey performed in 1980,[59] did not have an ASHRAE-based code for residential construction in 1980.

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[56]Telephone interview with Jim L. Heldenbrand of ASHRAE (7/13/95).

[57]Thedifficulty in determining the actual level of implementation is confounded by the fact that the level of code compliance is not identical to the level of code enforcement. "California studies showing [energy] code enforcement at 70 percent to 80 percent in the buildings surveyed, also found that the level of compliance actually exceeded the code." (From draft report on *Quality Metrics Impact Assessment*, by Jeff Johnson, Building Standards and Guidelines Program, Pacific Northwest National Laboratory, November 1995).

[58]Battelle Pacific Northwest Laboratories, "Current State Code Status," from Department of Energy Report to Congress, October 1995.

[59]National Conference of States on Building Codes and Standards, Inc., *1980 Federal and State Actions in Energy Codes, Standards, Legislation and Regulations*, January 1981, and *State Energy Code Activity Over the Last Five Years*, May 1994. Also "Introduction to Energy Codes," *Southern Building*, September/October 1994.

(2) The initial level of adoption for each region at the end of 1974 (equal to the beginning of 1975) is determined by the construction of single-family residences in those states that, according to information from ASHRAE and Battelle PNL already had either enacted legislation or built residential housing incorporating energy conservation measures before BFRL became involved in developing ASHRAE 90-75.[60] The initial level of adoption for the region is thus weighted by that percentage of new construction in the region that is built according to energy conservation measures. In the West, for example, it was California that determined the initial level of conservation activity. It had enacted energy conservation legislation by 1974 and its construction of single-family residences constituted 45.1 percent of the region's total.

(3) The final level of adoption in 1980 is based on information from the 1980 survey by NCSBCS. It excludes all new construction in those states that had no residential energy code at that time, or whose energy code was not based on ASHRAE 90-75. It also excludes construction in those states with considerable energy conservation activity in 1974 and whose savings after 1974 could, therefore, not clearly be credited to ASHRAE 90-75.

(4) The rate of adoption and the rate of implementation are considered to be identical for the baseline analysis. A 50 percent implementation rate is considered in the sensitivity analysis.

The adoption levels and rates calculated with these assumptions are listed in table 5-5. The average annual rate of adoption of ASHRAE 90-75 is simply the difference between the initial level of energy conservation activity and the final level of adoption of ASHRAE 90-75, divided by the six years from the beginning of 1975 to the end 1980.

It is estimated that in the Northeast, for example, 38 percent of residential construction was subject to at least some energy conservation activity by the beginning of 1975, either mandatory or voluntary. By the end of 1980, about 70 percent of residential construction in the Northeast was covered by an ASHRAE 90-75-related energy conservation code, representing a net average annual rate of increase over the six years of 5.4 percent, directly related to ASHRAE 90-75. The net average annual rates of adoption of ASHRAE 90-75 in the Midwest, South, and West were derived in a similar fashion.

To estimate BFRL's contribution, we make the assumption that without BFRL's development effort, it would have taken until at least 1984 for 70 percent of residential construction in the Northeast to be covered by an equivalent energy conservation code. The BFRL contribution to the energy cost savings achieved by ASHRAE 90-75 is calculated by applying the difference between the actual adoption rate and the delayed adoption rate to the potential cost savings. The graph in figure 5-1 depicts those differences for the Northeast.

[60] Mr. J. L. Heldenbrand of ASHRAE (8/8/95 and 1/22/96) and Mr. R. M. Martin of the California State Energy Commission (1/22/96) suggested that the following states were active in residential energy conservation at that time: Massachusetts, New York, Wisconsin, Minnesota, Florida, and California.

Table 5-5. Adoption Levels and Average Annual Rate of Adoption of Energy Conservation Codes, 1975 and 1980

Adoption Level	Northeast	Midwest	South	West
Initial adoption level: Construction covered by non-ASHRAE 90-75-related energy conservation code; beginning of 1975	37.6%	20.2%	19.0%	45.1%
Final adoption level: Construction covered by ASHRAE 90-75-related energy conservation code; end of 1980	70.0%	48.7%	62.2%	89.3%
Average annual rate of adoption: for ASHRAE 90-75-related energy conservation codes; beginning of 1975 to end of 1980	5.4%	4.8%	7.2%	7.3%

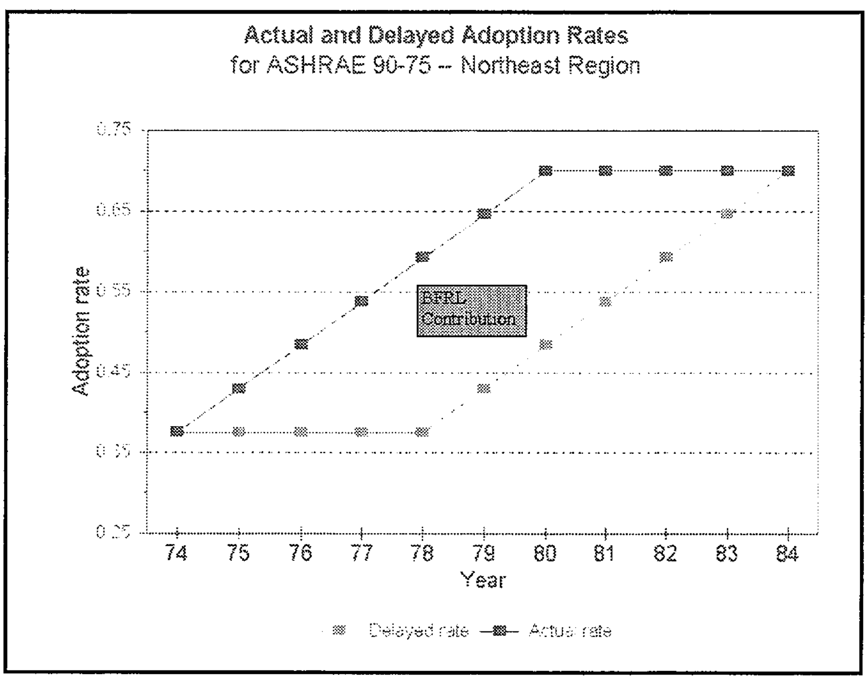

Figure 5-1. Comparison of Adoption Rates With and Without BFRL's Development of ASHRAE 90-75

The actual level of adoption goes from 38 percent in 1974 to 70 percent in 1980. With the assumed four-year delay, the level of adoption would have gone from 38 percent in 1978 to 70 percent in 1984. The vertical distance between the actual and delayed rates represents the percentage difference due to the earlier adoption of ASHRAE 90-75. For the Northeast it is 5.4 percent in the first year of the study period, 10.8 percent in the second year, and so on through the relevant period. These percentage differences are listed in table 5-6 for each year and all four geographical regions. They will be applied to total potential savings in each region to measure BFRL's contribution.

5.3 Energy Cost Savings Nationwide

Total potential energy cost savings are the basis from which actual ASHRAE 90-75-related savings and the BFRL contribution are calculated. Actual savings are that proportion of total potential savings actually realized from ASHRAE 90-75, based on its rate of adoption. The BFRL contribution is that proportion of total potential savings realized by "avoiding" a four-year delay in the adoption of the standard.

Table 5-6. Differences Between Actual and Delayed Adoption Rates for ASHRAE 90-75
(in percent of total potential)

Year	Northeast	Midwest	South	West
1974	0.0	0.0	0.0	0.0
1975	5.4	4.8	7.2	7.3
1976	10.8	9.6	14.4	14.5
1977	16.2	14.4	21.6	21.8
1978	21.6	19.2	28.8	29.1
1979	21.6	19.2	28.8	29.1
1980	21.6	19.2	28.8	29.1
1981	16.2	14.4	21.6	21.8
1982	10.8	9.6	14.4	14.5
1983	5.4	4.8	7.2	7.3
1984	0.0	0.0	0.0	0.0

5.3.1 Potential Energy Cost Savings

The present value of total potential energy cost savings in 1975 dollars for the years from 1975 to 1984 is calculated for each geographical area, using the following formula:

$$PPVS_{75}^{g} = \sum_{t=1}^{10} [(S_t^{g} \times UPV_{t,e}^{*}) \times SPV_{t,75}], \tag{3.1}$$

where

$PPVS^g_{75}$	=	the present value, as of 1975, of potential energy cost savings that would have accrued in geographical area g if all single-family residences constructed from 1975 to 1984 had been built according to ASHRAE 90-75, where g_1 = Northeast, g_2 = Midwest, g_3 = South, and g_4 = West.
S^g_t	=	total potential energy costs savings in year t for region g, calculated by multiplying the total number of square meters of new construction (from table 5-4) by the ADL-calculated base-year savings/m^2 (from table 5-2), escalated by the annual real change in fuel prices (from table 5-3, column (3));
$UPV^*_{t,e}$	=	the Modified Uniform Present Value factor, (from table 5-3, column (4)), computed as of the year of construction t over a period of ten years from the year of construction, with a real discount rate d of 10 percent[61] and modified by the real change in energy prices e (from table 5-3, column (2));
$SPV_{t,75}$	=	the Single Present Value factor,[62] computed using a real discount rate d of 10 percent, to convert each present value amount in year t to a present value amount at the base date of 1975.

Table 5-7 (left column) lists total potential energy cost savings for each year in each of the four geographical regions and for the U.S. as a whole. If all new construction of single-family residences from 1975 to 1984 had been covered by ASHRAE 90-75, a total of approximately $5.5 billion in 1975 PV dollars would have been saved through energy cost reductions. In 1995 PV dollars this estimate amounts to about $15.6 billion.[63]

5.3.2 Actual Energy Cost Savings

Table 5-7 (right column) also lists the actual energy cost savings attributable to ASHRAE 90-75 for the four geographical regions and the U.S. as a whole. These savings are calculated by multiplying the actual adoption rate for ASHRAE 90-75 in each year from 1975 to 1984 by the potential energy savings in each year. For example, in the Northeast actual ASHRAE-related energy savings in 1976 are $17.5 million, the product of the potential energy savings of $162.3 million and the actual adoption rate for ASHRAE 90-75 of 10.8 percent, where 10.8 percent is the difference between the actual level of adoption of ASHRAE 90-75 in 1976 of 48.4 percent less the initial already existing level of energy conservation activity of 37.6 percent. For the year 1980, that level of adoption would be 32.4 percent (= 0.70 - 0.376).

[61] In 1975, the base date of this study, a discount rate of 10 percent, excluding inflation, was in effect for evaluating time-distributed costs and benefits of government projects, as determined by the Executive Office of the President, Office of Management and Budget, *Circular A-94*.

[62] ASTM, *ASTM Standards on Building Economics*, Table 10.

[63] All amounts are converted to 1995 dollars by using the Consumer Price Index for Fuels (1982-1984 = 100).

Table 5-7. Estimated Potential and Actual Energy Cost Savings from ASHRAE 90-75 in Single-Family Residences, 1975-84
(in millions of 1975 PV-$)

Year	Northeast		Midwest		South		West		Total U.S.	
	Savings Potential	Savings Actual	Savings Potential	Savings Actual	Savings Potential	Savings Actual	Savings Potential	Savings Actual	Savings Potential	Savings Actual
75	157.8	8.5	106.8	5.1	195.4	14.1	117.3	8.6	577.3	36.3
76	162.3	17.5	130.2	12.5	213.3	30.7	147.0	21.5	652.8	82.2
77	177.1	28.7	138.9	20.0	259.6	56.0	189.4	41.3	765.0	146.1
78	177.2	38.3	133.1	25.6	266.8	76.8	211.2	61.5	788.3	202.1
79	166.4	44.9	122.5	29.4	237.5	85.5	181.2	66.0	707.7	225.8
80	118.7	38.5	67.8	19.5	192.4	83.1	118.7	51.9	497.7	193.0
81	101.0	32.7	53.1	15.3	162.2	70.1	91.0	39.8	407.3	157.9
82	83.7	27.1	32.4	9.3	125.7	54.3	58.0	25.3	299.8	116.1
83	104.2	33.8	47.6	13.7	161.5	69.8	87.4	38.2	400.7	155.4
84	118.6	38.4	49.0	14.1	158.3	68.4	97.5	42.6	423.3	163.5
Total PV$ (1975)[a]	**1,366.9**	**308.4**	**881.5**	**164.4**	**1,972.7**	**608.8**	**1,298.8**	**396.5**	**5,519.8**	**1,478.3**

[a]Because of rounding, totals are not exact sums of annual amounts.

For the U.S. as a whole, the estimated energy cost savings in single-family residences from ASHRAE 90-75 for the period from 1975 to 1984 amounted to $1.5 billion in 1975 PV dollars. In 1995 dollars this amount is approximately $4.2 billion.

5.4 BFRL Contribution

5.4.1 Baseline Analysis

To calculate the BFRL contribution, the differences, in percent, between the actual and the assumed delayed adoption rates of table 5-6 are multiplied by the potential PV energy cost savings of table 5-7, for every year for each of the four geographical regions. The resulting amounts are then summed over years and regions to arrive at the total BFRL contribution to energy cost savings from ASHRAE 90-75 in single-family houses in the U.S. All amounts are expressed in 1975 present-value dollars.

Table 5-8 shows these results for the four regions and for the U.S. as a whole. To use the Northeast as an example again, the dollar value of BFRL's contribution to total actual savings of $308.4 million (table 5-7) was $185.6 million (table 5-8), in 1975 present-value dollars, for the period from 1975 to 1984.

Table 5-8. BFRL Contribution to Energy Cost Savings in New Single-Family Residences, 1975-84
(in millions of 1975 PV-$)

Year	Northeast	Midwest	South	West	Total U.S.
74	0.0	0.0	0.0	0.0	0.0
75	$8.5	$5.1	$14.1	8.6	$36.3
76	17.5	12.5	30.7	21.3	82.2
77	28.7	20.0	56.1	41.3	146.1
78	38.3	25.6	76.8	61.5	202.1
79	36.0	23.5	68.4	52.7	180.6
80	25.7	13.0	55.4	34.6	128.6
81	16.4	7.6	35.0	19.8	78.9
82	9.0	3.1	18.1	8.4	38.7
83	5.6	2.3	11.6	6.4	25.9
84	0.0	0.0	0.0	0.0	0.0
Total PV$ (1975)[a]	**185.6**	**112.8**	**366.3**	**254.6**	**919.4**

[a] Because of rounding, totals are not exact sums of annual amounts.

The BFRL contribution to energy cost savings from ASHRAE 90-75 for the period from 1975 to 1984 for the U.S. as a whole amounts to a total present value of $919.4 million in 1975 dollars. This constitutes about 62 percent of the total actual energy cost savings nationwide of $1.5 billion. Expressed in 1995 dollars, the present value of the BFRL contribution as of 1975 is $2.6 billion of a total of actual ASHRAE 90-75-related savings of $4.2 billion.

Figure 5-2 shows for each year of the study period a graphical representation of the BFRL contribution (from table 5-8) in relation to actual present value savings (from table 5-7), based on the four-year avoidance of the delay in the issuance and adoption of ASHRAE 90-75. As the graph shows, BFRL is credited for 100 percent of the total actual cost savings attributable to the standard for the four years from the beginning of 1975 to the end of 1978 and for partial, diminishing savings for the years from 1979 to 1984. BFRL is not credited with any energy cost savings beyond 1984.

Present Value Net Savings (PVNS), Savings-to-Investment-Ratio (SIR), and Adjusted Internal Rate of Return (AIRR) are useful measures for determining the efficiency of an investment in a given project:

- PVNS is a measure of present value savings when benefits occur primarily in the form of cost reductions. For a project to be cost-effective, present value net savings has to be positive.
- The SIR expresses the ratio of savings from the project per dollar of investment. For a project to be cost effective, the SIR has to be greater than one.

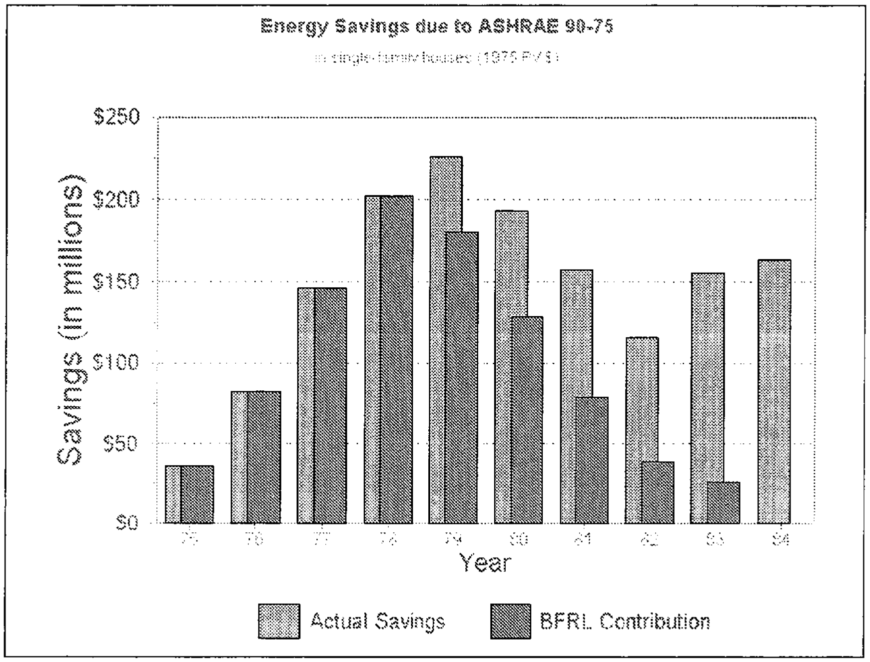

Figure 5-2. BFRL Contribution Compared with Total Actual Energy Cost Savings

- The AIRR is a measure of the annual percentage yield from a project investment over the study period. For an investment to be cost effective, the AIRR has to be greater than the minimum acceptable rate of return, which in our case is the discount rate.

All of these measures have been described in detail in chapter 3.

5.4.1.1 Present Value Net Savings

The present value research and development costs (PV costs) incurred by NIST for BFRL's participation in developing ASHRAE 90-75 is estimated to have amounted to approximately $367,000 in 1975 present value dollars.[64] Deducting the—for all practical purposes negligible—investment of $367,000 from the BFRL contribution of $919.4 million, we arrive at net benefits to the nation of about $919 million in 1975 present-value dollars. It needs to be kept in mind that the relatively small investment cost incurred by BFRL covers only the standard-making development work strictly related to developing the test procedures and guidelines upon which ASHRAE 90-75 is based. It does not include the cost of the research that had been

[64]BFRL's investment in ASHRAE 90-75 amounted to about $300,000 over a relatively short period between 1973 and 1975. We assume that the costs were incurred uniformly from 1973 through 1975, and we use the discount rate of 10 percent (real) and the Consumer Price Index to adjust the amount to present value at the base date, i.e., to $367,000 in 1975 present value dollars. Note also that this amount is the cost of BFRL's ASHRAE-related development work for all types of buildings, not only for single-family residences. It therefore represents the higher bound in our cost calculations and contributes to a conservative estimate of net savings.

conducted at NIST over many years in the areas of building technology and energy use and which was the main reason why BFRL was in a unique position to standardize the test procedures and to issue guidelines for energy conservation in buildings on short notice.

5.4.1.2 Savings-to-Investment Ratio

An SIR of 2505 (=$919.4/0.367) implies that for every dollar spent by BFRL on ASHRAE-related activities $2,505 were saved in energy costs in single-family residences built between 1975 and 1984 in the U.S. An SIR of 2505 is quite high, but nevertheless plausible if one considers that close to a million single-family residences are built in the U.S. every year and that the cost to BFRL was the marginal cost of applying its basic-research results to one additional project.

5.4.1.3 Adjusted Internal Rate of Return

Using the simplified AIRR formula, with a discount rate of 10 percent as the reinvestment rate, and the SIR calculated above as one of the terms, we compute the AIRR on BFRL's investment over the study period of 22 years as follows:

$$AIRR = (1 + d) \cdot SIR^{1/22} - 1$$
$$AIRR = (1 + 0.10) \cdot 2505^{1/22} - 1$$
$$= 0.57 = 57\%$$

The AIRR of 57 percent is the social rate of return on BFRL's investment, that is, the annual yield over the study period of BFRL's research investment leading to energy cost savings in single-family residences throughout the U.S. over the period from 1975 to 1994.

Table 5-9 summarizes the evaluation measures of BFRL's contribution to energy cost savings in single-family residences.

Table 5-9. Summary of Evaluation Measures—Baseline Analysis

Estimates of Energy Cost Savings as of 1975 ($-amounts in millions)	1975-$	1995-$
PVS: Total actual ASHRAE 90-75-related savings	1,478	4,183
PVS: BFRL contribution to energy cost savings	919.4	2,602
PVNS: Net BFRL contribution	919.0	2,602
SIR: BFRL contribution	2,505	
AIRR: BFRL contribution	57%	

5.4.2 Sensitivity Analysis

The calculation of time-distributed benefits and costs is typically sensitive to the assumptions made about uncertain data. Chapter 2, section 2.4 describes how sensitivity analysis can be used in a deterministic or probabilistic mode to take into account this uncertainty in the analysis results. In our study we limit ourselves to performing a deterministic sensitivity analysis, that is, we simply recalculate benefits and costs using different values of the uncertain variables.

5.4.2.1 Sensitivity of Results to Delay in Issuance and Adoption of ASHRAE 90-75

In this study, the least certain of the variables is the lag in the issuance and adoption of a generally accepted energy conservation code if BFRL had not participated in its development. The assumption that BFRL advanced the adoption of a standard by at least four years is a plausible one, but to provide a conservative lower bound, we recalculate the net savings, assuming that without BFRL's participation the adoption of a standard would have been delayed by only two years instead of the originally assumed four years.

Table 5-10 shows the re-estimated energy cost savings. Under the assumption of a two-year delay in the issuance and adoption of a consensus code, BFRL's total contribution to energy cost savings in the U.S. for single-family residences constructed from 1975 to 1984 is reduced from $919.4 million to $498.3 million. The corresponding net savings is $497.9 million in 1975 PV dollars ($1.41 billion in 1995 dollars), the benefit-cost ratio is 1358, and the adjusted internal rate of return is 52 percent. These results show that even with the rather conservative assumption of only a two-year delay in the adoption of ASHRAE 90-75, BFRL makes a significant impact per dollar of investment.

For the sake of comparison we make the even more conservative assumption of a delay of only one year.[65] Table 5-12 at the end of this section includes the results calculated under the assumption of a one-year delay. Even if the issuance and adoption of ASHRAE 90-75 had been delayed by only one year without BFRL's participation, BFRL could still be credited with contributing a present value amount of $254 million to energy cost savings over the period from 1975 to 1984. An SIR of 692 and an AIRR of 48 percent would still make BFRL's investment in ASHRAE 90-75 a highly worthwhile project.

5.4.2.2 Sensitivity of Results to Level of Implementation

Since there are no reliable data available as to what proportion of new single-family construction in each year of the study period complied with energy code requirements in each state, we also test for a level of implementation of 50 percent compared with the assumed 100 percent implementation in the baseline

[65] It is not very likely that it would have been possible without BFRL's participation to finalize such a standard, or equivalent national legislation, by 1976, even though, or rather because, all state governments were under intense pressure to pass energy conservation legislation in the wake of the 1973 oil crisis. One of the main reasons why NIST was called into action by NCSBCS was to prevent the proliferation of non-consistent energy conservation rules that were under consideration in numerous states in the early 1970s. Without the independent and authoritative leadership of NIST, it is more likely that it would have taken more than the assumed four years to arrive at a standard acceptable to all the states involved.

Table 5-10. Sensitivity Analysis: BFRL Contribution to Energy Cost Savings Assuming a Two-Year Delay in the Adoption of ASHRAE 90-75
(in millions of 1975 PV-$)

Year	Northeast	Midwest	South	West	Total U.S.
74	0.0	0.0	0.0	0.0	0.0
75	$8.5	$5.1	$14.1	$8.6	$36.3
76	17.5	12.5	30.7	21.5	82.2
77	19.1	13.3	37.4	27.7	97.5
78	19.1	12.8	38.4	30.8	101.2
79	18.0	11.8	34.2	26.5	90.4
80	12.8	6.5	27.7	17.3	64.4
81	5.5	2.6	11.7	6.6	26.3
82	0.0	0.0	0.0	0.0	0.0
83	0.0	0.0	0.0	0.0	0.0
84	0.0	0.0	0.0	0.0	0.0
Total PV $ (1975)[a]	**100.6**	**64.6**	**194.2**	**139.0**	**498.3**

[a]Because of rounding, totals are not exact sums of annual amounts.

estimates. We recalculate the four economic measures—PVS, PVNS, SIR, AIRR—assuming a 50 percent implementation and a four-year, two-year, and one-year delay. A 50 percent implementation means that only half of the baseline energy cost savings can be attributed to ASHRAE 90-75. Hence the BFRL contribution likewise is reduced by one half from the 100 percent implementation level. The most conservative scenario of a one-year lag and a 50 percent implementation gives a PVNS for the BFRL contribution of $127 million nationwide. The corresponding annual and total estimates are listed in table 5-11 for the regions and the U.S. An SIR of 346 and an AIRR of 43 percent result from these savings and the BFRL investment costs (see summary in table 5-12).

5.4.2.3 Other Considerations

Some further assumptions underlying this analysis that cause the estimate of BFRL's contribution to be on the conservative side are the following:

- The estimated savings span ten years, but a case could be made that the energy cost savings from ASHRAE 90-75 continue into the present, especially since the Energy Policy Act of 1992 requires that all states review and revise their codes to meet or exceed the standards established by ASHRAE 90-75 and its revisions.

- Because the study period ended before any major revisions to the standard took place, the estimates exclude the increase in savings that the more stringent requirements of the

Table 5-11. Sensitivity Analysis: BFRL Contribution to Energy Cost Savings Assuming a One-Year Delay in the Adoption of ASHRAE 90-75 and a 50 Percent Implementation
(in millions of 1975 PV-$)

Year	Northeast	Midwest	South	West	Total U.S.
74	0.0	0.0	0.0	0.0	0.0
75	$4.3	$2.6	$7.0	$4.3	$18.1
76	4.4	3.1	7.7	5.4	20.6
77	4.8	3.3	9.3	6.9	24.4
78	4.8	3.2	9.6	7.7	25.3
79	4.5	2.9	8.6	6.6	22.6
80	3.2	1.6	6.9	4.3	16.1
81	0.0	0.0	0.0	0.0	0.0
82	0.0	0.0	0.0	0.0	0.0
83	0.0	0.0	0.0	0.0	0.0
84	0.0	0.0	0.0	0.0	0.0
Total PV $ (1975) [a]	**25.9**	**16.8**	**49.1**	**35.2**	**127.1**

[a]Because of rounding, totals are not exact sums of annual amounts.

revised standard achieved by inducing homeowners to switch to cheaper fuels or to install more efficient HVAC equipment.[66]

- The estimates are a partial estimate of BFRL's contribution to energy cost savings in buildings since it applies only to single-family residences. Similar calculations could be carried out for other types of buildings, such as apartment buildings, office buildings, retail stores, and school buildings, for which the savings from ASHRAE 90-75 were estimated by ADL to be even higher per square foot than for single-family residences.

- Finally, it is well known that other countries, especially Canada,[67] also base their energy conservation requirements in buildings on ASHRAE 90 standards. In our study, we focus on whether and to what degree BFRL's research and development work benefits the U.S. Benefits accruing from ASHRAE 90-75 outside the U.S. are therefore not included in our estimates, but they still add to the value of BFRL's research efforts.

[66]The most recent revisions of ASHRAE 90-75 are ASHRAE/IES 90.1-1989 *Energy Efficient Design of New Buildings Except New Low-Rise Residential Buildings* and ASHRAE 90.2-1993 *Energy-Efficient Design of New Low-Rise Residential Buildings.*

[67]See, for example, references to ASHRAE 90-1, vol. 1, no. 11, of the *Advanced Building Newsletter,* Royal Architectural Institute of Canada, January 1996.

5.5 Summary of Findings

Table 5-12 summarizes the baseline estimates and the results of each of the scenarios of the sensitivity analysis. The shaded area shows the baseline estimates, which used the most plausible assumptions with respect to the adoption and implementation of ASHRAE 90-75 and with respect to BFRL's contribution to energy cost savings. The remainder of the table summarizes the results of the sensitivity analysis.

From the results of the baseline calculations it is clear that the issuance and adoption of ASHRAE 90-75 had a significant impact on energy cost savings in buildings throughout the U.S., leading to total present-value savings of almost $1.5 billion in single-family residences from 1975 to 1984. Over $900 million of these savings were directly attributable to the BFRL activities that promoted the development of ASHRAE 90-75. The SIR of 2505 and the AIRR of 57 percent testify to the cost effectiveness of BFRL's investment in this project, which is maintained even under the most conservative assumptions.

The economic measures—PVNS, SIR, and AIRR—reported in this chapter demonstrate the high impacts from BFRL's contribution in the development and adoption of ASHRAE 90-75. There are several reasons why these impact measures have high values.

First, at the time when the research project which provided the technical basis for ASHRAE 90-75 was initiated, BFRL had an active program of relevant "focused" research already underway and well established. BFRL's staff not only possessed the skills required to conduct the research but had easy access to test facilities and other support services needed to complete the project in a timely manner. Since BFRL's research program and core competencies were already well established, it was possible to undertake this "new" research project at a very low marginal cost. Costs, however, are only one component of the analysis. BFRL's research investment in the development and adoption of ASHRAE 90-75 had significant impacts because it leveraged private sector activities in a very efficient manner.

Second, NCSBCS and ASHRAE had already articulated a need for design criteria to use as the technical basis for a consensus standard. BFRL's contribution involved gaining consensus among all key stakeholders while the technical report was being developed. This approach recognized at the outset that the overarching goal was the production of a consensus standard and not just a "good" technical report.

Third, by achieving consensus quickly, BFRL significantly speeded the adoption of the consensus standard by ASHRAE. Faster adoption meant that energy cost savings began to accrue to the nation at an earlier date than would have been possible otherwise.

Finally, BFRL's active collaboration with NCSBCS helped to disseminate results to the individual states in a highly efficient manner. Faster adoption, coupled with the use of existing distribution channels (e.g., ASHRAE and NCSBCS), resulted in impacts which were highly leveraged. Hundreds of thousands of single-family residences benefitted from the faster adoption of ASHRAE 90-75 and the cost savings associated with its energy-conserving features. They represent the tangible outcome of BFRL's contribution.

Table 5-12. Summary: BFRL Contribution to Energy Cost Savings from ASHRAE 90-75, 1975-1984

Part A: 100% Implementation[a]

Estimates of Energy Cost Savings as of 1975 ($-amounts in millions)	Four-year delay (Most likely)		Two-year delay (Conservative)		One-year delay (Least likely)	
	1975-$	1995-$	1975-$	1995-$	1975-$	1995-$
PVS: Total BFRL contribution	$919.4	$2,602	$498.3	$1,410	$254.1	$719
PVNS: Net BFRL contribution	$919.0	$2,601	$497.9	$1,409	$253.8	$718
SIR: BFRL contribution	2505		1358		692	
AIRR: BFRL contribution	57%		52%		48%	

Part B: 50% Implementation

Estimates of Energy Cost Savings as of 1975 ($-amounts in millions)	Four-year delay (Most likely)		Two-year delay (Conservative)		One-year delay (Least likely)	
	1975-$	1995-$	1975-$	1995-$	1975-$	1995-$
PVS: Total BFRL contribution	$459.7	$1,301	$249.1	$705	$127.0	$360
PVNS: Net BFRL contribution	$459.4	$1,300	$248.8	$704	$126.6	$359
SIR: BFRL contribution	1253		679		346	
AIRR: BFRL contribution	52%		48%		43%	

[a] The values resulting from the baseline analysis are shown in the shaded portion of the table.

6. 235 Shingles Case Study

6.1 Background

In 1958, the Tri-Services—a joint organization of the U.S. Army, Navy, and Air Force—who use asphalt roofing shingles extensively in their construction programs, asked BFRL to conduct research to replace the 210 asphalt shingle with a heavier, longer-lasting roofing shingle.[68] The 210 shingle was prone to a type of failure called "clawing" (twisted into the shape of grasping talons), which required frequent, costly roof replacements. The research conducted by BFRL between 1958 and 1960 recommended increased felt saturation and heavier back coating to provide a sufficient barrier to moisture infiltration. The resulting 235 shingle was subsequently adopted by the roofing industry as the new standard.[69] By 1962 about half and by 1970 about 98 percent of the shingles produced were of the heavier type.

It is likely that similar improvements would eventually have been made without BFRL's involvement, but its research and development activities contributed to an earlier acceptance of the voluntary shingle standard by the roofing industry. In the opinion of roofing industry experts, the availability and extensive use of 235 shingles would have been delayed from two to five years had it not been for BFRL's participation in, and coordination of, the development of the 235 shingle. A study performed in 1979, measuring the economic impact of substituting heavier shingles for lighter ones, defines this difference between the actual and the delayed rate of adoption as the basis for calculating the contribution of BFRL to the cost savings achieved nationwide from using the heavier, longer-lasting shingle.[70] The case study presented in this chapter summarizes the 1979 case study on shingles, adapting it to the approach outlined in chapters 2 to 4 for measuring economic impacts. The 1979 case study used the present value of net savings (PVNS) and the internal rate of return (IRR) to first measure the social payoff nationwide of substituting 235 shingles for 210 shingles, and, secondly, to evaluate the efficiency of BFRL's investment in the development and implementation of the 235 shingles standard. In this report we are replacing the IRR with the adjusted internal rate of return (AIRR). An explicit calculation of the savings-to-investment ratio (SIR) is also included.

The study estimated that during a 13-year period from 1962 to 1974 the total present value savings to consumers in the U.S. from the increased life of the 235 shingle amounted to approximately $3.9 billion in 1974 dollars. Without BFRL's participation, the savings would have been approximately $2.2 billion.

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[68] The designation for the type of shingle—210 and 235—reflects the weight per sales square. A sales square—the customary unit by which shingles are sold—is the quantity of shingles needed to cover 100 square feet of roofing surface, e.g., 210 lbs. or 235 lbs. Throughout this report, we use the number associated with weight per sales square—210 and 235—to designate the type of shingle under analysis. This method of designation reflects roofing industry practices throughout the United States.

[69] NIST cooperated with the American Roofing Manufacturers' Association (ARMA), the American Society for Testing and Materials (ASTM), and Underwriters' Laboratories (UL) towards an immediate revision of consensus shingle standards. ASTM and UL standards were updated by April 1962. (Telephone interview (12/7/95) with William C. Cullen, National Roofing Contractors Association and former head of BFRL's Building Materials Division).

[70] Marshall and Ruegg, *Efficient Allocation of Research Funds.*

Exhibit 6-1. Summary of Economic Impacts of BFRL Research on 235 Shingles

1.a Significance of Research Effort:

Use of the lighter-weight 210 shingle (a shingle weighing 210 lbs. per square (SQ), i.e., per unit of sale equal to 100 sq.ft. of roof area) contributed to a type of roofing failure called "clawing," which resulted from moisture absorption of the reinforcing organic felt. The average life of the shingle was 10 years, but roofs often failed after 2 to 4 years. Since over 80% of sloped roofs in the U.S. are covered with asphalt shingles, the poor durability was a serious and costly problem for homeowners, businesses, and military bases across the nation.

In 1958 BFRL (then CBT) was asked by Tri-Services to investigate the defect. Its research showed that a thicker asphalt coating and greater saturation of the felt would prevent clawing and provide more protection from moisture penetration. These recommendations resulted in the 235 shingle which was adopted by the roofing industry as the new standard in 1962. The heavier shingle lasts at least 15 years in hot climates and more than 20 years in cooler climates, a gain in expected useful life of at least 5 years. The additional cost of the shingle was estimated to be $1.60/SQ.

In the opinion of roofing experts, the availability and extensive use of the heavier shingle would have been delayed from 2 to 5 years had it not been for BFRL's participation in, and coordination of, the development and promotion of the 235 shingle.

1.b Key Points:

- Lighter-weight 210 shingle lasted an average of only 10 years necessitating frequent roof replacements.
- BFRL research resulted in the heavier 235 shingle with a life of 15 to 20 years, at an additional cost of $1.60 per square.
- BFRL's participation advanced the development and implementation of a heavier shingle and the acceptance of an improved roofing shingle standard by 2 - 5 years.

2. Analysis Strategy:

The main objective of the study is to measure the economic impact of BFRL's participation in the development of the heavier, improved shingle. The approach is to estimate *ex post* the following quantities:

(1) **Present Value Savings** (PVS) that accrued to the nation as a whole, over the period from 1962 to 1974, by substituting 235 shingles for 210 shingles. The estimates are based on an estimated rate of adoption, the total annual shingle production, and a cost savings of $0.835/SQ per year for the 235 shingle due to its longer life.

(2) **PVS attributable to BFRL**'s research and development of the improved shingle by calculating the difference between the nationwide PVS and the (lesser) savings that could have been achieved without BFRL's participation.

(3) **PV Net Savings** (PVNS), the difference between savings and project costs, both for the nation as a whole and for BFRL's contribution.

(4) **Savings-to-Investment Ratio** (SIR), the ratio of total savings to total investment costs for the nation as a whole and for the BFRL contribution. A ratio > 1 indicates an economically worthwhile project.

(5) **Adjusted Internal Rate of Return** (AIRR), the annual return on investment over the study period, for the nation as a whole and for the BFRL contribution. An AIRR > the discount rate indicates that the project is economically worthwhile.

Data and Assumptions:

- The study period begins in 1958 and ends in 1974; investment costs by BFRL and other groups are incurred between 1958 and 1960; savings accrue from 1962 to 1974, i.e., 13 years. The length of the study period is thus 17 years.
- The base year is 1974 and all savings and costs are expressed in 1974 dollars.
- The useful life is 15 years for 235 shingles and 10 years for 210 shingles. Base-year annualized life-cycle cost savings per square of 235 shingles are based on labor and materials costs in 1974 and on continuous roof replacement.
- The adoption rate of the new shingle standard is estimated on the basis of roofing industry information.
- The discount rate is 10 percent (real), which is the OMB real discount rate in effect for government projects in 1974.
- Without BFRL's participation, the conversion to the 235 shingle would have been delayed by 3 years.
- The Consumer Price Index for all items (1982-84 =100) is used to convert amounts to 1995 dollars.

3.a Calculation of Savings, Costs, and Additional Measures:

Evaluation measures nationwide:

PV Savings nationwide:
Sum of (rate of adoption * quantity of shingles * annual savings/ SQ * UCA) = $3,921.3 million

PV Costs nationwide are the combined investment of BFRL and other groups: $155,700 + $778,700 = $0.934 million

PV Net Savings nationwide is the difference between total PVS and total PV costs in millions:
$3,921.3 - $0.934 = $3,920.4 million

SIR nationwide: $3,921.3/$0.934 = 4198

AIRR nationwide: $(1+0.10)\ 4198^{1/17} - 1 = 0.80$

Evaluation measures for BFRL contribution:

PV Savings attributable to BFRL:
PVS nationwide minus PVS nationwide with 3-year delay
$3,921.3 - $2,193.0 = $1,728.3 million

PV Net Savings attributable to BFRL:
Difference between total savings attributable to BFRL and cost of BFRL research and development work:
$1,728.3 - $0.156 = $1,728.1 million

SIR of BFRL contribution: $1,728.3/$0.156 = 11079

AIRR of BFRL contribution:
$(1+0.10)\ 11079^{1/17} - 1 = 0.90$

3.b Key Results:

Savings Nationwide:

	1974-$	1995-$
	($-amounts in millions)	
PVS	$3,921.3	$12,122
PV Costs	$0.934	$ 2.888
PVNS	$3,920.4	$12,119
SIR	4198	
AIRR	80%	

Savings Attributable to BFRL:

	1974-$	1995-$
PVS	$1,728.3	$5,343
PV Costs	$0.156	$0.482
PVNS	$1,728.1	$5,342
SIR	11079	
AIRR	90%	

The difference of $1.7 billion represents BFRL's contribution ($5.3 billion in 1995 dollars). The present value costs of BFRL's activities, incurred between 1958 and 1960, are estimated to be $156 thousand, and the AIRR corresponding to these savings and costs is 97 percent per year over the period between 1958 and 1974. Exhibit 6.1, which utilizes the framework introduced in chapter 4, provides an extended summary of the background, approach, and results of the study.

6.2 Approach

6.2.1 Methodology

The economic impact of the 235 shingle specification is expressed as four different measures, namely total present value savings (PVS), present value net savings (PVNS), savings-to-investment ratio (SIR), and adjusted internal rate of return (AIRR). These measures will be calculated for the savings from the improved shingle to consumers nationwide and for the portion of savings specifically attributable to BFRL's research and development activities.

The first step in the evaluation process is to measure and compare the life-cycle costs of the two types of shingles to determine, if and by how much the 235 shingles cost less to the owner of a building for which they are used. This difference in life-cycle costs is taken to be the annual cost savings that can be achieved by using the 235 shingle. *Total cumulative present value cost savings* from all 235 shingles produced in the U.S. over a certain period will be taken as a measure of gross benefits nationwide. This is thought to be a fairly accurate measure of social benefits.

Total cumulative present value *net savings* of the shingle will be found by subtracting from its total savings the total costs of implementing the new shingle. These costs consist of research and development, and dissemination-of-information costs incurred by BFRL as well as by other groups with which BFRL coordinated research efforts.

BFRL's contribution is defined as the *total present value cost savings* due to BFRL's involvement in the research and development of the 235 shingle. It is calculated assuming that without BFRL's involvement the adoption of the 235 shingle would have been delayed by three years. *Present value net savings from BFRL's research* is derived by subtracting BFRL research costs from the total contribution attributable to BFRL.

The *savings-to-investment ratios* and the *adjusted internal rates of return* are calculated on the combined investment by BFRL and other groups and separately on BFRL's investment alone.

6.2.2 Data and Assumptions

6.2.2.1 Length of Study Period

The 17-year study period begins in 1958 and ends in 1974. Any costs and savings beyond 1974 are not included.

The following factors determined the beginning and end of the study period:

(1) The study period begins in 1958, which is approximately the time when BFRL and other groups became involved in the development of the standard. Most of the costs for the research and development work that NIST and other groups performed were incurred between 1958 and 1960. The specifications for the 235 shingle were completed by the end of 1961 and the new standard was available early in 1962. The savings from the 235 shingles are measured beginning in 1962. Costs and savings are brought forward to 1974, and all present value amounts are expressed in 1974 dollars.

(2) The end of the evaluation period, the year 1974, coincides with the emergence of synthetic fibers. In the mid-1970's, the roofing industry began manufacturing more and more inorganic shingles, that is, shingles with fiberglass "felts" rather than (organic) cotton felts, so that the problem of clawing became less prevalent. Any type of thinner shingle is now made with inorganic felts. Nevertheless, the 235 to 240 shingle is still the standard for the heavier type of organic shingle.[71]

6.2.2.2 Base-Year Annual Cost Savings from 235 Shingles

A measure of annual savings per unit of shingle is necessary to calculate the value of the expected stream of savings that accrued to consumers over the 13-year period from the quantity of shingles sold in each of the 13 years. The price of the various types of asphalt shingles generally varies proportionately to their weight. Similar shingles undergo a similar production process, but heavier shingles contain more materials. Thus the 235 shingle costs more than the 210 shingle. The 1974 price per sales square was $15 for materials for the 235 shingle and $13.40 for the 210 shingle. The labor cost of $20 for initial installation was the same for either type of shingle. Consequently, consumers had to pay an additional $1.60 in order to obtain a sales square of shingles of the 235 type. The objective of the evaluation is to determine whether this additional cost of $1.60 per sales square in return for five more years of roofing life was a worthwhile investment.

Since it is not obvious which shingle actually costs more per unit of time over its life, the first step in the evaluation is to measure and compare the life-cycle costs of the two types of shingles. By computing life-cycle costs in terms of the annual costs of a unit of each type of shingle and then comparing them, the annual per unit savings of a 235 over a 210 shingle can be derived.

Table 6-1 shows the computation of the uniform annual cost savings from 235 shingles. Part I of the table calculates the uniform annual cost for the 235 shingle, assuming that it will last 15 years; part II calculates the annual cost for the 210 shingle, assuming that it will last 10 years. The difference of $0.835 between the annual cost of $5.438 for the 210 shingle and $4.603 for the 235 shingle represents the base-year annual cost savings per sales square (in 1974 dollars) of substituting 235 shingles for 210 shingles.

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[71] A larger and larger part of the asphalt shingles market now consists of laminated multi-layered organic or inorganic shingles, an altogether different shingle. Market data from ARMA show that in 1993 only about 9 percent of the shingles market consisted of organic 235-240 asphalt shingles. (Telephone interview with Mr. Peter Kelly, Director of Public Affairs, ARMA, 12/7/1995).

Table 6-1. Calculation of Annual Cost Savings to Consumers from Substituting a Unit of 235 Shingles for a Unit of 210 Shingles

I.	Calculation of Uniform Annual Cost per sales square of 235 shingles (AC_{235}), assuming a 15-year life, continuous roof replacement, and a 10% discount rate: AC_{235} = $(L_{235} + M_{235})$ (UCR, i = 10%, N = 15) = (\$20 + \$15) (0.1315) = **\$4.603/SQ**
II.	Calculation of Uniform Annual Cost per sales square of 210 shingles (AC_{210}), assuming a 10-year life, continuous roof replacement, and a 10% discount rate: AC_{210} = $(L_{210} + M_{210})$ (UCR, i = 10%, N = 10) = (\$20 + \$13.40) (0.1628) = **\$5.438/SQ**
III.	Calculation of Uniform Annual Cost Savings per sales square (ACS_{235}) of substituting 235 shingles for 210 shingles, where ACS_{235} = $AC_{210} - AC_{235}$ ACS_{235} = \$5.438/SQ - \$4.603/SQ = **\$0.835/SQ**

Source: Marshall and Ruegg, *Efficient Allocation of Research Funds.*

Note: The calculation of the annual cost (AC_k) of one sales square of shingles, assuming continuous roof replacement,[72] uses the following formula

$$AC_k = (L_k + M_k) \frac{i(1+i)^N}{(1+i)^N - 1}$$

where

L_k	=	labor cost of installing one sales square of type k shingles, in 1974 dollars
M_k	=	materials cost of one sales square of type k shingles, in 1974 dollars
i	=	real discount rate
N_k	=	life of type k shingles, in years, and
$\frac{i(1+i)^N}{(1+i)^N-1}$	=	uniform capital recovery formula (UCR)

[72]The assumption of continuous roof replacement avoids having shingle life conform to building life, which would result in biased costs for one shingle type relative to the other. For a detailed discussion of this assumption, see Marshall and Ruegg, *Efficient Allocation of Research Funds.*

6.2.2.3 Discount Rate

Throughout the analysis a real discount rate of 10 percent is used to convert dollar amounts to present values. This rate was in effect in 1974, the base date of the analysis, for evaluating time-distributed government projects.

6.2.2.4 Quantity of 235 Shingles and Rate of Adoption

In order to calculate the total present value savings from 235 shingles, the annual savings per square are multiplied by the quantity of shingles used in each year. Two assumptions are made with respect to the quantity of 235 shingles used in each year: (1) In the absence of purchase data, the quantity of shingles produced is used as a proxy for the quantity purchased and applied to roofs.[73] (2) Because the 235 shingle replaces the 210 shingle, the quantity of shingles produced and sold remains the same despite the fact that the price of the 235 shingle is somewhat higher.

6.2.2.5 Adoption Rate of 235 Shingles Standard

Roofing industry experts estimated that because the failure of the 210 shingle had already been a serious problem for some time, a large segment of the industry began producing the heavier shingle almost immediately after the new shingle specifications became available in 1962. The assumption of an immediate 50 percent adoption level in 1962 is based on the following reasoning: In general, shingle production can fairly quickly be adjusted to changes such as higher asphalt saturation of the felt and thicker coating. Further, during that time, the market was dominated by about a dozen large manufacturers capable of following on short notice the industry leader in adapting their production to new, and more competitive, processes. The conversion to 235 shingles was considered essentially complete by 1970.[74] The *rate* of adoption of the 235 shingle between 1962 and 1970 was estimated on the basis of information provided by the roofing industry.

6.3 Values of Selected Evaluation Methods

6.3.1 Present Value Savings to Consumers Nationwide

In order to obtain a measure of total present value savings (PVS) to consumers nationwide from substituting 235 for 210 shingles over the 13 years from 1962 through 1974, the annual savings per sales square are multiplied by the quantity of 235 shingles sold in each year, and the resulting 13 streams of annual savings are then converted to a present value equivalent. Table 6-2 shows the steps in this calculation: (1) The figures in column (6) show the annual savings that accrue in each of the 13 years over the study period (column (6) = (2) x (3) x (5)). For example, the savings per batch of $15.3 million in 1962 (= 50 percent of the total quantity of 36,606 thousand squares times the *annual* cost savings per square of

[73] Exports of asphalt shingles in general amount to less than 5 percent of the total quantity of shingles produced in the U.S. Exports of 235 shingles during the relevant time period are assumed to be neglible. (Telephone interview with Peter Kelly, ARMA, 4/23/96 and Yolanda Griepentrog, Export Division, Schuller Products International, Denver, 4/24/96.)

[74] Telephone interviews (12/9/95) with Ray Corban of Schuller Products International, Denver, CO , and Bob Lilleston of GS Roofing Products Co., Wilmington, CA (12/5/95).

Table 6-2. Present Value Savings to Consumers from 235 Shingles

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Year	**235 as % of total shingles**	**Total quantity of shingles (SQ) in thousands**	**Quantity of 235 shingles (SQ) in thousands**	**Annual cost savings/S Q ($)**	**Annual cost savings per batch in millions of 1974-$**	**Present value factors (UCA)**	**Present value of annual cost savings in millions of 1974-$**
			(2) x (3)		(4) x (5)		(6) x (7)
1962	50	36,606	18,303	0.835	15.3	24.520	374.7
1963	60	36,078	21,647	0.835	18.1	21.380	886.4
1964	80	40,162	32,130	0.835	26.8	18.530	497.1
1965	95	39,748	37,809	0.835	31.6	15.940	503.2
1966	95	36,830	34,989	0.835	29.2	13.580	396.7
1967	96	42,038	40,356	0.835	33.7	11.440	385.5
1968	97	43,307	42,007	0.835	35.1	9.487	332.8
1969	97	46,208	44,822	0.835	37.4	7.716	288.8
1970	98	45,489	44,579	0.835	37.2	6.105	227.2
1971	98	54,588	53,497	0.835	44.7	4.641	207.3
1972	98	58,518	57,348	0.835	47.9	3.310	158.5
1973	98	63,420	62,151	0.835	51.9	2.100	109.0
1974	98	65,956	64,637	0.835	54.0	1.000	54.0
Total present value savings[a] (in millions of 1974-$) = **$3,921.3**							

[a]Because of rounding, the total is not exact sum of the annual amounts.

Source: Marshall and Ruegg, *Efficient Allocation of Research Funds.*

$0.835) will accrue in every one of the 13 years from 1962 to 1974; the annual savings in 1973 will accrue in the two remaining years from 1973 to the end of the evaluation period. (2) Each stream of annual savings is converted to a present value equivalent (column (8)). This is done by applying the uniform compound amount factor[75] (column (7)) to the annual cost savings (column (6)). The uniform compound amount factor is the appropriate factor for converting a stream of past annual amounts to the present, which is the case here. For example, at an adoption level of 50 percent, the 18.3 million squares of 235 shingles

[75]The uniform compound amount factor is derived from the uniform compound amount formula, where an end-of-period payment (A) times the UCA factor for the appropriate discount rate (I) gives future value (F) of (A) over (n) discount periods:

$$F = A \frac{(1+i)^n - 1}{i}$$

sold in 1962 yield total present value savings of about $374.7 million over the 13 years; at an adoption level of 98 percent, the 62.2 million squares of shingles sold in 1973 yield total present value savings of about $109 million for the two remaining years in the evaluation period.

By summing the present value savings associated with each year's consumption of 235 shingles, we arrive at an estimate of total present value savings for the 13-year period of $3.9 billion, in 1974 dollars. In 1995 dollars this present value amount is approximately $12.1 billion.

6.3.2 Net Savings to Consumers Nationwide

To calculate the present value of *net savings* to consumers nationwide from using 235 shingles instead of 210 shingles, the estimated total present-value costs of introducing 235 shingles are deducted from the estimated total present value savings to consumers nationwide. Most research on 235 shingles, by BFRL and other organizations, occurred between 1958 and 1960. Expenditures on research by BFRL amounted to between $15,000 and $20,000. Other organizations are estimated to have spent between $50,000 and $100,000 over the same period. Converting these amounts, which are stated in 1958-60 dollars, to 1974 dollars requires taking into account the effect of inflation before discounting to present value.[76] Consumer price indices are used to express the expenditures in 1974 dollars, and the single compound amount factor, calculated with a discount rate of 10 percent, is used to bring the values forward in time.[77]

To simplify calculations, it is assumed that one quarter of the research funds were used each in 1958 and 1960 and one half in 1959. To avoid understatement of the expenditures, the upper end of the estimated range is used. Expressed in 1974 dollars, expenditures amount to $33,799 for BFRL and to $169,030 for other groups. Multiplying these expenditure figures by the single compound amount factor we get $155,700 and $778,700 respectively in present value dollars. The total cost of research nationwide, adjusted for inflation and expressed in present value terms, thus amounts to about $934,400 in 1974 dollars.

Table 6-3 derives the estimated present value net savings to consumers nationwide by subtracting the total present value of research expenditures from the total present value of consumer cost savings. Since the investment costs in relation to the total savings are very small, the difference between total present value savings and present value net savings is negligible, leaving present value net savings nationwide at about $3.9 billion in 1974 dollars and $12.1 billion in 1995 dollars.

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[76] In the case of *savings* it was not necessary to adjust for inflation when converting them to the present values shown in table 6.2 because annual cost savings were stated in 1974 dollars at the outset.

[77] The Single Compound Amount formula for the appropriate discount rate (i) calculates the future value (F) of a present amount (P) over (n) discount periods:

$$F = P(1+i)^n$$

Table 6-3. Calculation of Net Savings to Consumers from 235 Shingles
(in millions of 1974-$)

Present value cost savings from 235 shingles	=	$3,921.3
(minus)		
Present value cost of introducing 235 shingles	=	$0.934
(equals)		
Present value net savings from 235 shingles	=	**$3,920.4**

6.3.3 Savings-to-Investment Ratio: Nationwide

As explained in chapter 3, section 3.2, the SIR (eq (3.7)) is a variation of the Benefit-to-Cost Ratio (BCR) and is often used instead of the BCR when benefits occur primarily as cost reductions. An SIR of greater than one indicates a cost-effective project. The SIR to the nation as a whole of switching from 210 shingles to 235 shingles is simply the ratio of the total present value savings to the total present value investment costs, that is,

$$SIR = \frac{\$3,921.3}{\$0.934}$$
$$= 4198.$$

An SIR of 4198 means that over the period from 1958 to 1974 each dollar invested in developing the 235 shingle specifications produced cost savings to consumers nationwide of $4,198 in 1974 present value dollars.

6.3.4 Adjusted Internal Rate of Return

6.3.4.1 Adjusted Internal Rate of Return: Nationwide

The internal rate of return (IRR) measures the economic performance of an investment as a percentage yield. It is the compound rate of interest that equates the flow of costs of a project with the flow of savings. Here we are estimating the "adjusted" internal rate of return, which takes into account the reinvestment rate of net cash flows (see chapter 3, section 3.3). An AIRR greater than the discount rate indicates a cost-effective project. When the SIR is known, the AIRR can be calculated using eq (3.17). Using this formula, the AIRR on the combined investment by BFRL and other organizations in generating savings can be estimated as follows, using the 10 percent discount rate as the reinvestment rate and the SIR calculated in 6.3.3:

$$AIRR_{235} = (1 + 0.10)\, 4198^{1/17} - 1$$
$$= \mathbf{0.797 = 80\%}$$

An AIRR of 80 percent is the social rate of return on the investment expenditures on 235 shingles, incurred by BFRL and other groups.[78] Since it is significantly higher than the minimum acceptable rate of return implied by the discount rate, it indicates that the investment was well worthwhile.

Table 6-4 summarizes the values of the evaluation measures for the cost savings from 235 shingles to consumers nationwide.[79]

Table 6-4. Summary of Evaluation Measures of Cost Savings Nationwide

Measures of Evaluation		Estimates of Cost Savings from 235 Shingles, as of 1974 ($-amounts in millions)	
		1974-$	**1995-$**
PVS:	**Total cost savings nationwide**	**$3,921.3**	**$12,122**
PVNS:	**Net savings nationwide**	**$3,920.4**	**$12,119**
SIR		**4198**	
AIRR		**80%**	

6.3.4.2 Adjusted Internal Rate of Return: Individual Homeowner

It is of interest to compare the rate of return represented by the AIRR of 80 percent on the combined investment of BFRL and other groups with the private rate of return on the investment a homeowner would have to make if she bought 235 shingles instead of 210 shingles. To calculate the private AIRR we first calculate the SIR, assuming

- a 10-year time horizon,
- a 10 percent discount rate, and
- an initial investment cost in 1974 dollars of $33.40/SQ for the 210 shingle and $35.00/SQ for the 235 shingle.

Since the useful life of the 210 shingle is ten years and that of the 235 shingle 15 years, the 235 shingle would have 1/3 of its useful life remaining at the end of ten years. Given that the initial investment cost of a square of 235 shingles is $35.00 and assuming a linear depreciation schedule, we set the residual value at $11.55. After discounting this amount to the beginning of the study period, the present value savings due

[78]Because the research expenditures were incurred between 1958 to 1960, the yield rate on the investment is calculated over the full 17 years of the study period, including the years 1958 to 1962.

[79]The 1974 dollar amounts were converted to 1995 dollar amounts by applying the Consumer Price Index for All Items (All Urban Consumers, 1982-1984 = 100), U.S. Department of Labor, Bureau of Labor Statistics.

to the longer life of the 235 shingle is \$4.45 (= $11.55/1.10^{10}$). The ratio of these present value savings to the additional investment cost of \$1.60/SQ (= \$35.00 - \$33.40) required for purchasing 235 shingles, is an SIR for 235 shingles of 2.78. The AIRR is then calculated as follows:

$$\begin{aligned} \text{AIRR} &= (1 + 0.10)\, 2.78^{1/10} - 1 \\ &= 0.2186 \\ &= 21.9\% \end{aligned}$$

Since the AIRR of 21.9 percent is more than twice the assumed minimum acceptable rate of return (as expressed by the discount rate), the additional cost of \$1.60 per square for the 235 shingle would be a worthwhile investment for the homeowner.

6.4 BFRL Contribution

In order to isolate the economic impact of BFRL research activities with respect to 235 shingles, we estimate the portions of total present value savings (PVS) and present value net savings (PVNS) that are attributable specifically to BFRL's involvement. The SIR and AIRR for the BFRL contribution to the savings will also be calculated.

6.4.1 Baseline Analysis

6.4.1.1 Total Cost Savings Attributable to BFRL Research

To estimate the total cost savings attributable to BFRL research, we compare the total present value savings to consumers over the 13-year period from 1962 to 1974 with and without BFRL involvement. To do this, present value savings from 235 shingles are re-estimated, assuming that BFRL advanced their application by three years. This assumption takes approximately the middle value of our best guess of two to five years. Hence, the level of production (and consumption) is lagged by three years so that savings begin to accumulate in 1965 instead of 1962. In order to get a measure of the value of BFRL's involvement, we calculate the difference between the actual savings and the savings that would have been achieved without BFRL's involvement.

In table 6-5 it is assumed that without BFRL involvement the quantity of 235 shingles prior to 1965 would have been negligible, and that each year, beginning in 1965, the percentage of the market comprised of 235 shingles would have paralleled that for the period 1962 to 1974 with BFRL involvement. Following the same procedure as in table 6-2, the estimate of total present value savings to consumers from 235 shingles without BFRL would have amounted to about \$2,193 million in 1974 dollars. Table 6-6 then takes the difference between the results with BFRL involvement (table 6-2) and those without (table 6-5) to show that an estimated \$1.7 billion of the \$3.9 billion of present value consumer savings, or about 44 percent, can be credited to BFRL's involvement in developing the improved shingle. In 1995 dollars, this amount is about \$5.3 billion.

Table 6-5. Present Value Savings to Consumers from 235 Shingles Without BFRL Involvement

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Year	**235 as % of total shingles, without BFRL**	**Total quantity of 235, without BFRL (SQ) in thousands**	**Annual cost savings per SQ ($)**	**Annual cost savings per batch, without BFRL ($) in millions of 1974-$**	**Present value factors UCA**	**Present value of annual cost savings, without BFRL ($) in millions of 1974-$**
				(3) x (4)		(5) x (6)
1962-64	0	0	0	0	--	--
1965	50	19,899	0.835	16.6	15.940	264.9
1966	60	22,098	0.835	18.5	13.580	250.6
1967	80	33,630	0.835	28.1	11.440	321.2
1968	95	41,141	0.835	34.4	9.487	325.9
1969	95	43,898	0.835	36.7	7.716	282.8
1970	96	43,669	0.835	36.5	6.105	222.6
1971	97	52,951	0.835	44.2	4.641	205.2
1972	97	56,673	0.835	47.4	3.310	156.9
1973	98	62,151	0.835	51.9	2.100	109.0
1974	98	64,637	0.835	54.0	1.000	54.0
Total present-value savings, without BFRL (in 1974-$) =						**$2,193.0**

Source: Marshall and Ruegg, *Efficient Allocation of Research Funds.*

Table 6-6. Present Value Savings to Consumers from 235 Shingles Due to BFRL Involvement
(in millions of 1974-$)

Total present value savings from 235 shingles	=	$3,921.3
(minus)		
Present value savings from 235 shingles without BFRL involvement	=	$2,193.0
(equals)		
Present value savings attributable to BFRL involvement	=	**$1,728.3**

Table 6-7. Present Value Net Savings from 235 Shingles Due to BFRL Involvement
(in millions of 1974-$)

Present value cost savings attributable to BFRL	=	**$1,728.3**
(minus)		
Present value costs of BFRL activities	=	**$0.156**
(equals)		
Present value net savings attributable to BFRL involvement	=	**$1,728.1**

6.4.1.2 Net Savings of BFRL's Contribution

The net savings of BFRL's contribution is calculated by subtracting the cost of BFRL's research and development for the 235 shingle from the share of savings attributed to BFRL. Because the investment expenditure incurred by BFRL was relatively small, the present value net savings attributable to BFRL differs very little from the total present value contribution. It must be remembered that, although other groups together spent more than BFRL, BFRL played a key role in that it led the development of the new standard, coordinated the work of the different groups, and promoted acceptance of the standard.

6.4.1.3 Savings-to-Investment Ratio for BFRL Contribution

Taking the ratio of the savings to costs allows us to calculate the SIR for the BFRL contribution as 11079. This means that each dollar of BFRL investment in developing specifications for an improved shingle saved $11,079 in present value terms to consumers nationwide over the 17-year period.

6..4.1.4 Adjusted Internal Rate of Return on BFRL Contribution

Inserting the SIR of 11079, a 10-percent discount rate, and a 17-year study period into the formula in eq (3.17) of section 3.3, we calculate an AIRR of 90 percent on BFRL's contribution as follows:

$$\text{AIRR} = (1+0.10)*11079^{1/17} - 1$$
$$= \mathbf{0.902} = \mathbf{90\%}$$

The large total present value savings to consumers nationwide and the extremely favorable impact of BFRL's contribution are to be expected, given that millions of squares of 235 shingles were sold each year and that each square is estimated to have reduced roofing costs by more than 80 cents per year. The relatively low cost incurred by BFRL for developing the shingle specifications is due to the fact that BFRL, who can draw on the results of many years of roofing materials research, does not charge to this type of project any costs related to its basic research. In this case, only the costs directly related to furthering the development and acceptance of the 235 shingle as a voluntary standard are taken into account.

The evaluation measures calculated for the portion of savings attributable to BFRL's involvement in the research and development of the 235 shingle are summarized in table 6-8.

Table 6-8. Summary of Evaluation Measures of Cost Savings Attributable to BFRL

Measures of Evaluation	Estimates of Cost Savings from 235 Shingles, as of 1974 ($-amounts in millions)	
	1974-$	**1995-$**
PVS: BFRL contribution to cost savings nationwide	$1,728.3	$5,343
PVNS: BFRL contribution to net savings nationwide	$1,728.1	$5,342
SIR: BFRL contribution	11079	
AIRR: BFRL contribution	90%	

6.4.2 Sensitivity Analysis

The results of the evaluation may be sensitive to the particular assumptions that have been made with respect to the discount rate, the service life of 235 shingles, and other key variables. The 1979 study examined the sensitivity of net savings to changes in some of these assumptions. The results of that sensitivity analysis are briefly described here.

6.4.2.1 Breakeven Analysis for Length of Service Life of 235 Shingles

The assumption of a longer service life for 235 shingles is crucial to the findings of positive net savings and acceptable rates of return on the investment. The original estimates of savings are based on an advantage of 5 years for the 235 shingles. To find out how much advantage in service life is required to make the life-cycle costs of 235 shingles equal to those for 210 shingles, the breakeven life of 235 shingles is determined. Based on a 10-year life for 210 shingles and a discount rate of 10 percent, the breakeven point is found to occur between 10 3/4 and 11 years. This means that 235 shingles need last not even a full year longer than 210 shingles in order to justify their additional purchase price. The probability of 235 shingles being cost effective must therefore be quite high, since they were found to often last considerably more than 5 years longer than 210 shingles.

6.4.2.2 Sensitivity Analysis Using a Conservative Scenario

In this conservative scenario, the sensitivity analysis recalculates PVS, PVNS, SIR and AIRR, assuming a shorter service life advantage of 235 shingles over 210 shingles (2 years instead of 5 years), a lower

discount rate (2 percent instead of 10 percent),[80] and a shorter delay in acceptance of 235 shingles without BFRL involvement (1 year delay instead of 3 years). The recalculated evaluation measures are summarized in table 6-9. Cost savings are about $1.4 billion to consumers nationwide, and $1.2 billion without BFRL's involvement, reducing BFRL's present value net contribution to about $199 million. The corresponding SIR for BFRL's contribution in this case computes to 1277 and the AIRR to 72 percent. Even in this conservative scenario, BFRL's investment in developing shingle specifications has a very high payoff.

6.5 Summary of Findings

The conclusions to be drawn from these results are that the adoption of 235 shingles to replace the failing 210 shingles had a tremendous impact on roofing costs, resulting in present value savings to consumers of nearly $4 billion over the 13-year period from 1962 to 1974. The BFRL activities that promoted the development and adoption of 235 shingles were directly responsible for more than $1.7 billion of the savings. Note that these benefits and rates of return are calculated on one single investment—in this case one with a very favorable return. The return on the investment budget for a large R&D program with many projects could be expected to fall below these rates, since some projects are likely to fail completely and lower the average project return. Table 6-9 summarizes the results of the baseline analysis and the sensitivity analysis and lists the values of the economic measures for the savings to consumers nationwide and for the BFRL contribution. The shaded parts list the results of the baseline analysis for the savings to consumers nationwide and for the BFRL contribution.

The economic measures—PVNS, SIR, and AIRR—reported in this chapter demonstrate the high impacts from BFRL's contribution in the development and adoption of 235 shingles. There are several reasons why these impact measures have high values.

First, at the time when the research project which led to the development of 235 shingles was initiated, BFRL had an active program of relevant "focused" research already underway and well established. BFRL's staff not only possessed the skills required to conduct the research but had easy access to test facilities and other support services needed to complete the project in a timely manner. Since BFRL's research program and core competencies were already well established, it was possible to undertake this "new" research project at a very low marginal cost. Costs, however, are only one component of the analysis. BFRL's research investment in the development and adoption of 235 shingles had significant impacts because it leveraged private sector activities in a very efficient manner.

Second, the problem of "clawing" associated with the 210 shingle was widely recognized. Consequently, the roofing industry was already looking for an alternative to the 210 shingle. Due to BFRL's expertise in this area, the Tri Services sought it out as the logical candidate for solving the problem of clawing. In addition, BFRL was already highly regarded as an authority in this area by the private sector. Therefore, once BFRL had completed its research effort, its findings were quickly adopted as specifications by the roofing industry. The end result of these new specifications was the introduction of the 235 shingle in 1962.

[80] Since in this case the amounts are compounded forward to the year 1974 to convert past annual savings and costs to present value equivalents, the higher discount rate increases present value savings whereas the lower discount rate of 2 percent decreases present value savings.

Third, roofing experts estimate that BFRL speeded up the adoption of the 235 shingle by at least two years and perhaps by as much as five years. Faster adoption meant that building owners which installed the 235 shingle could expect less frequent roof replacements.

Finally, BFRL's active ties with the roofing industry produced an additional source of leverage. Because BFRL was both well known and respected by key stakeholders within the roofing industry *and* the roofing industry was dominated by several large building material manufacturers, the 235 shingle penetrated the roofing market very quickly. The number of building owners which adopted the 235 shingle, once it became available, and the savings they could anticipate through less frequent roof replacements are an indication of the value of BFRL's contribution.

Table 6-9. Summary: Economic Impact from Substituting 235 Shingles for 210 Shingles

Part A: Cost Savings to Consumers Nationwide[a]

Estimates of Cost Savings as of 1974 ($-amounts in millions)	5-year longer service life, 10% discount rate, 3-year delay in adoption (Most likely)		2-year longer service life, 2% discount rate, 1-year delay in adoption (Conservative)	
	1974-$	1995-$	1974-$	1995-$
PVS: Total PV cost savings to consumers nationwide	$3,921.3	$12,122	$1,406.7	$4,348
PVNS: PV net savings to consumers nationwide	$3,920.4	$12,120	$1,405.9	$4,346
SIR	4196		1505	
AIRR	80%		74%	

Part B: PV Cost Savings to Homeowner

Estimates of Cost Savings (amounts in $ per SQ)	10-year study period, 10-percent discount rate	
	1974-$	1995-$
PVS: Value of longer life	$4.45	$13.76
SIR	2.78	
AIRR	21.9%	

Part C: BFRL Contribution to PV Cost Savings[a]

Estimates of Cost Savings as of 1974 ($-amounts in millions)	5-year service life, 10% discount rate, 3-year delay in adoption (Most likely)		2-year longer service life, 2% discount rate, 1-year delay in adoption (Conservative)	
	1974-$	1995-$	1974-$	1995-$
PVS: Total PV cost savings to consumers nationwide	$1,728.3	$5,343	$198.9	$615
PVNS: PV net savings to consumers nationwide	$1,728.1	$5,3432	$198.7	$614
SIR: BFRL contribution	11079		1277	
AIRR: BFRL contribution	90%		72%	

[a]The values resulting from the baseline analysis are shown in the shaded portion of the table.

7. Summary and Suggestions for Further Research

7.1 Summary

A formal resource allocation process for research is needed in both the public and private sectors. Research managers need guidelines for research planning so that they can maximize the payoffs from their limited resources. Furthermore, quantitative descriptions of research impacts have become a basic requirement in many organizations for evaluating budget requests.

The National Institute of Standards and Technology (NIST), a scientific research agency of the U.S. Department of Commerce's Technology Administration, is improving its resource allocation process by doing "microstudies" of its research impacts on society. This report is the first of a series of impact studies prepared by NIST's Building and Fire Research Laboratory (BFRL). It focuses on building technology applications—ASHRAE 90-75 and 235 shingles. The second report in the series, focuses on a fire technology application—the Fire Safety Evaluation System for health care facilities.[81] This report is presented in a general framework so that it can be adopted for application by any government agency allocating research funds, and in some cases, by universities and private research firms as well.

This report has four major purposes. First, it examines five standardized evaluation methods for measuring the economic impacts of research investments. Second, it establishes a framework for identifying, classifying, quantifying, and analyzing the benefits and costs of research investments. Third, it provides a generic format for summarizing the economic impacts of research investments. Fourth, it illustrates—by way of two case studies of building technologies—how the framework, evaluation methods, and generic format would be applied in practice.

Chapters 2 through 4 establish the basic methodology for measuring the economic impacts of a research project, of a research program, or of a new technology. Because the material in chapters 2 through 4 emphasizes an approach that is applicable to economic impact studies in general, it begins with an overview of benefit-cost analysis. Four key concepts are then introduced and outlined. First, the need to identify and classify benefits and costs is discussed. Second, a mathematical formulation is given. The mathematical formulation provides the vehicle for mapping benefits and costs into each of the standardized methods described in chapter 3. Next, a series of technical considerations are discussed. These considerations include such important topics as the need to discount benefits and costs to an equivalent time basis for purpose of comparison, the challenges of estimating benefits and costs, and the crucial role of data in developing such estimates. Finally, how the use of sensitivity analysis permits the effects of uncertainty to be evaluated is discussed.

The five standardized methods for measuring the economic impacts of research investments are described in chapter 3. Each standardized method is derived from the mathematical formulation given in chapter 2. Since investment decisions often differ in their objectives, chapter 3 concludes with an analysis of when, and under what circumstances, it is appropriate to use each standardized method.

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[81] Chapman and Weber, *A Case Study of the Fire Safety Evaluation System.*

Two case studies of building technologies are developed in Chapters 5 and 6. The first case study, described in Chapter 5, provides estimates of the economic impacts from past BFRL research leading to the introduction of the ASHRAE 90-75 standard for residential energy conservation. The energy costs of the ASHRAE 90-75 standard are compared to those of pre-1973 oil embargo energy standards. The case study estimates the energy savings from ASHRAE 90-75 modifications in single-family residences constructed over the period from 1975 through 1984. The issuance of ASHRAE 90-75 had a significant impact on energy cost savings in buildings throughout the United States, leading to a total present value of net savings of almost $1.5 billion in 1975 dollars in single-family residences from 1975 to 1984. Over $900 million of these present value net savings were directly attributable to the BFRL activities that promoted the development of ASHRAE 90-75.

The second case study, described in Chapter 6, provides estimates of the net dollar savings from a past research effort in the development of an improved asphalt shingle for sloped roofing. The costs of the improved shingle are compared against the costs of the shingle it displaced. Net savings are computed for the actual quantity of the improved shingle that was installed during the period from 1962 to 1974. The adoption of the longer-lasting 235 shingles to replace the failing 210 shingles had a significant impact on roofing costs, resulting in a present value of net savings to consumers of nearly $4 billion in 1974 dollars over the 13-year period from 1962 to 1974. The BFRL activities that promoted the development and adoption of 235 shingles were directly responsible for more than $1.7 billion of the present value of net savings to consumers over that 13-year period.

In both case studies, the results measured are for a specific research project. Consequently, they can *neither* be extrapolated to other specific research projects *nor* to BFRL's research program as a whole. Extrapolating to other specific research projects is at best a risky proposition. As is noted in the section which follows, more work is needed in several areas to develop a better understanding of how to measure economic impacts. To even begin to get a measure of the return on BFRL's overall research program, it would first be necessary to perform a "portfolio" of project impact studies.

7.2 Suggestions for Further Research

The background work for this report uncovered additional areas of research that might be of value to government agencies and other institutions that are concerned with an efficient allocation of their research budgets. These areas of research are concerned with: (1) the development of a standard classification of research benefits and costs; (2) factors affecting the diffusion of new technologies; (3) conducting *ex ante* evaluations with scheduled follow-ups; and (4) evaluations based on multiattribute decision analysis.

7.2.1 The Development of a Standard Classification of Research Benefits and Costs

A recently published survey by the Civil Engineering Research Foundation shows that expenditures for research and development efforts in the areas of construction, building, and disaster mitigation technologies were over $2.1 billion in 1992.[82] Private industry, trade association, university, and government research bodies would like to know what are the economic impacts of these investments. The standardized evaluation methods—present value of net benefits, present value of net savings, benefit-to-cost ratio, savings-to-investment ratio, and adjusted internal rate of return—described in this report are appropriate for measuring these economic impacts. However, there is no systematic and comprehensive classification

[82] Civil Engineering Research Foundation. 1993. *A Nationwide Survey of Civil Engineering-Related R&D*. Report no. 93-5006. Washington, DC: Civil Engineering Research Foundation.

of research benefits and costs to guide analysts who must identify the benefits and costs associated with new construction, building, and disaster mitigation technologies that are used in these standardized evaluation methods. Such a classification, if developed, refined, and adopted as a standardized classification, could be used in several ways.[83] First, the classification will help researchers and research managers identify potential benefits and costs associated with candidate research projects and thereby help them choose those with maximum net benefits (maximum net savings). Second, the classification will provide a standardized basis for identifying benefits and costs in research proposals. Finally, the classification will make possible a consistent treatment of benefits and costs in *ex ante* evaluations of new technologies and in *ex post* evaluations of completed building- and fire-related research projects.

7.2.2 Factors Affecting the Diffusion of New Technologies

Reliable estimates of the data input values for the standardized evaluation methods cannot be made without some relatively sound basis for predicting the rate of diffusion and the ultimate level of adoption of a new technology. The rate of diffusion and the ultimate level of adoption of a new technology depend on many factors. Uncertainty about how a new technology will perform affects both its rate of diffusion and its ultimate level of adoption.

Two factors over which a research laboratory exerts some control and which have the potential to reduce uncertainty about new technologies are: (1) the research laboratory's information dissemination efforts; and (2) the research laboratory's participation in standards-making organizations. Additional research on these two factors is warranted for a number of reasons. First, the characteristics of information are changing dramatically. With the advent of the World Wide Web and the increased acceptance of electronic media, the fruits of research may be quickly and widely disseminated. The reliance on printed reports sent to a targeted audience as the sole vehicle for communication is being eclipsed by other means of information dissemination. This transition needs to be studied to ensure that the information dissemination strategy which emerges is tailored to the needs of the research laboratory's customer base. Second, research results in the form of technical reports often provide the basis for standards (e.g., BFRL's contribution to the ASTM standards on building economics). Consequently, information dissemination efforts may be used to leverage private-sector activities aimed at standardization. Finally, standards are an important means for disseminating information on expected levels of performance and for measuring key performance characteristics (e.g., through the use of standardized practices, specifications, and test methods). For new technologies, acceptance by a standards-making organization should lead both to higher rates of diffusion and to higher levels of adoption. Consequently, research on how a research laboratory's participation in standards-making organizations (e.g., those concerned with building codes and standards) affects the rates of diffusion and levels of adoption of new technologies will enable it to improve the efficiency with which it allocates staff and other resources to these activities.

[83] Although the standardized classification would be focused on identifying benefits and costs associated with building- and fire-related research projects, it would be generic to the extent that scientific research in general produces types of benefits and costs that are similar across technology areas. Thus the standardized classification will be applicable to many non-building- and non-fire-related technologies as well.

7.2.3 Conducting *Ex Ante* Evaluations with Scheduled Follow-ups

The two case studies on building technology presented in this report and the case study of the Fire Safety Evaluation System for hospital and nursing home occupancies presented in the companion document are *ex post* evaluations of completed building- and fire-related research projects. From an analysis perspective, an *ex ante* evaluation of a new technology poses several challenges which are absent in an *ex post* evaluation of a completed research project. The biggest challenge involves the diffusion of a new technology (i.e., predicting the rate of diffusion and the ultimate level of adoption). Although two of the factors affecting the diffusion of a new technology were discussed in the previous suggestion for further research, much can be learned about the diffusion process by performing *ex ante* evaluations with the understanding that scheduled follow-up evaluations will be conducted.

The follow-up evaluation will focus on answering several key questions. These questions are aimed at learning more about the research laboratory's role and ability to move research results towards the market place *and* about the way in which firms and households (i.e., the intended users of the new technology) adopt and make use of the new technology. First, did the new technology become available to the intended users when anticipated in the *ex ante* evaluation? Second, is the new technology being adopted at the rate anticipated? Third, are the users which adopt the new technology experiencing the types of changes anticipated (e.g., cost savings, increased durability, increased reliability)? Finally, are the types of users which adopt the new technology the same as anticipated? If these questions are asked and the answers are reviewed, critiqued, and fed back to research managers, *ex ante* evaluations will become a key link in the research laboratory's continuous improvement efforts.

7.2.4 Evaluations Based on Multiattribute Decision Analysis

Many research investment alternatives differ in characteristics that decision makers consider important but that are not readily expressed in monetary terms. Because the five standardized evaluation methods consider only monetary benefits and monetary costs associated with alternative research investments, their application does not reflect the importance of these non-financial characteristics to the decision maker. When non-financial characteristics are important, decision makers need a method that accounts for these characteristics (also called attributes) when choosing among alternative research investments. A class of methods that can accommodate non-monetary benefits and costs is multiattribute decision analysis.[84]

The analytical hierarchy process (AHP) is one of a set of multiattribute decision analysis methods that considers non-financial characteristics in addition to common economic evaluation measures (e.g., the five standardized evaluation methods) when evaluating project alternatives. The AHP has several important strengths: (1) it is well-known and well-reviewed in the literature; (2) it includes an efficient attribute weighting process; (3) it incorporates hierarchical descriptions of attributes; (4) its use is facilitated by available software; and (5) it has been accepted by ASTM as a standard practice for investments related to buildings and building systems.[85]

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[84] For more information on multiattribute decision analysis, see Norris, Gregory A., and Harold E. Marshall. 1995. *Multiattribute Decision Analysis Method for Evaluating Buildings and Building Systems.* NISTIR 5663. Gaithersburg, MD: National Institute of Standards and Technology.

[85] American Society for Testing and Materials. 1995. *Standard Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems.* E 1765. Philadelphia, PA: American Society for Testing and Materials.

The AHP and its associated software represent a powerful and versatile management tool. How to apply this management tool most productively in a research environment suggests additional research in two areas. First, what will be the relationship between the AHP software and the standard classification proposed earlier? Second, how will the AHP be used to assess fit to mission, to set priorities, or to evaluate performance against some other management goal? If research is conducted on the two topics just outlined, the AHP-based tool which emerges will provide a format for: (1) efficiently and reliably screening and selecting among alternative research investments (e.g., by embedding information from the standard classification of research benefits and costs, information on fit to mission, and on research priorities); (2) selecting research projects for in-depth analyses, either of the *ex ante* or *ex post* type of evaluation; and (3) selecting and scheduling follow-up evaluations.

References

American Society for Testing and Materials (ASTM). 1995. *Standard Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems.* E1765. Philadelphia, PA: American Society for Testing and Materials.

American Society for Testing and Materials (ASTM). 1994. *ASTM Standards on Building Economics.* Philadelphia, PA: American Society for Testing and Materials.

American Society for Testing and Materials (ASTM). 1993. *Standard Practice for Measuring Life-Cycle Costs of Building and Building Systems. E917.* Philadelphia, PA: American Society for Testing and Materials.

American Society for Testing and Materials (ASTM). 1993. *Standard Classification for Building Elements and Related Sitework—UNIFORMAT II. E1557.* Philadelphia, PA: American Society for Testing and Materials.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). 1993. *Energy Efficient Design of New Low-Rise Residential Buildings.* ASHRAE Standard 90.2-1993. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

American Society of Heating, Refrigerating and Air-Conditioning Engines, Inc. (ASHRAE). 1989. *Energy Efficient Design of New Buildings Except New Low-Rise Residential Buildings.* ASHRAE Standard 90.1-10989. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

American Society of Heating, Refrigerating and Air-Conditioning Engines, Inc. (ASHRAE). 1975. *Energy Conservation in New Building Design.* ASHRAE Standard 90-75. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Anderson, Lee G., and Russell F. Settle. 1977. *Benefit-Cost Analysis: A Practical Guide.* Lexington, MA: D.C. Heath and Company.

Arthur D. Little, Inc. 1975. *Energy Conservation in New Building Designs: An Impact Assessment of ASHRAE Standard 90-75.* Conservation Paper 43B. Cambridge, MA: Arthur D. Little, Inc.

Brown, Robert, and Carolyn Fitch. 1994. "Introduction to Energy Codes." *Southern Building* (September/October): pp. 29-31.

Chapman, Robert E., and Stephen F. Weber. 1996. *Benefits and Costs of Research: A Case Study of the Fire Safety Evaluation System.* NISTIR 5863 (In Press). Gaithersburg, MD: National Institute of Standards and Technology.

Chapman, Robert E. 1992. *Benefit-Cost Analysis for the Modernization and Associated Restructing of the National Weather Service.* NISTIR 4867. Gaithersburg, MD: National Institute of Standards and Technology.

References (continued)

Civil Engineering Research Foundation. 1993. *A Nationwide Survey of Civil Engineering-Related R&D.* Report No. 93-5006. Washington, DC: Civil Engineering Research Foundation.

Ehlen, Mark A., and Harold E. Marshall. 1996. *The Economics of New-Technology Materials in Construction: A Case Study of Composite Bridge Decking.* NISTIR 5864 (In Press). Gaithersburg, MD: National Institute of Standards and Technology.

Executive Office of the President. 1972. *Circular A-94.* Washington, DC: Office of Management and Budget.

Fuller, Sieglinde K., and Stephen R. Petersen. 1996. *Life-Cycle Costing Manual for the Federal Energy Management Program.* NIST Handbook 135. Gaithersburg, MD: National Institute of Standards and Technology.

Good, Mary, and Arati Prabhakar. 1994. "Foreword." In Mark Bello and Michael Baum, *Setting Priorities and Measuring Results at the National Institute of Standards and Technology.* Gaithersburg, MD: National Institute of Standards and Technology.

Harris, Carl M. 1984. *Issues in Sensitivity and Statistical Analysis of Large-Scale, Computer-Based Models.* NBS GCR 84-466. Gaithersburg, MD: National Bureau of Standards.

Johnson, Jeff. 1995. *Quality Metrics Impact Assessment: Building Standards and Guidelines Program.* Richland, WA: Pacific Northwest National Laboratory.

Loftness, Vivian, Jack J. Beckering, William L. Miller, and Arthur Rubin. *Re-valuing Buildings.* S5927. Grand Rapids, MI: Steelcase Inc.

Marshall, Harold E. 1995. *Choosing Economic Evaluation Methods—Part III in the Audiovisual Series on Least-Cost Energy Decisions for Buildings.* Gaithersburg, MD: National Institute of Standards and Technology.

Marshall, Harold E. 1995. *Least-Cost Energy Decisions for Buildings—Part III: Choosing Economic Evaluation Methods Video Training Workbook.* NISTIR 5604. Gaithersburg, MD: National Institute of Standards and Technology.

Marshall, Harold E. 1993. *Least-Cost Energy Decisions for Buildings—Part II: Uncertainty and Risk Video Training Workbook.* NISTIR 5178. Gaithersburg, MD: National Institute of Standards and Technology.

Marshall, Harold E. 1992. *Uncertainty and Risk—Part II in the Audiovisual Series on Least-Cost Energy Decisions for Buildings.* Gaithersburg, MD: National Institute of Standards and Technology.

References (continued)

Marshall, Harold E. 1988. *Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Building Investments.* NIST Special Publication 757. Gaithersburg, MD: National Institute of Standards and Technology.

Marshall, Harold E. 1986. "Advantages of the Adjusted Rate of Return." *Cost Engineering* (February): pp. 32-7.

Marshall, Harold E., and Rosalie T. Ruegg. 1979. *Efficient Allocation of Research Funds: Economic Evaluation Methods with Case Studies in Building Technology.* NBS Special Publication 558. Gaithersburg, MD: National Bureau of Standards.

National Bureau of Standards (NBS). 1974 (Revised 1976). *Design and Evaluation Criteria for Energy Conservation in New Buildings.* NBSIR 74-452. Gaithersburg, MD: National Bureau of Standards.

National Conference of States on Building Codes and Standards, Inc. 1994. *State Energy Code Activity Over the Last Five Years.* Herdon, VA: National Conference of States on Building Codes and Standards, Inc.

National Conference of States on Building Codes and Standards, Inc. 1981. *1980 Federal and State Actions in Energy Codes, Standards, Legislation and Regulations.* Herndon, VA: National Conference of States on Building Codes and Standards, Inc.

Norris, Gregory A., and Harold E. Marshall. 1995. *Multiattribute Decision Analysis Method for Evaluating Buildings and Building Systems.* NISTIR 5663. Gaithersburg, MD: National Institute of Standards and Technology.

Pacific Northwest National Laboratory. 1995. "Current State Code Status," from *Department of Energy Report to Congress.* Washington, D.C.: U.S. Department of Energy.

Reich, Robert W. 1989. "The Quiet Path to Technological Preeminence." *Scientific American* (October): pp. 41-7.

Reid, Laurie. 1996. "Consumer Gas Launches DSM." *Advanced Building Newsletter* (January): pp. 1-2.

Ruegg, Rosalie T., and Harold E. Marshall. 1990. *Building Economics: Theory and Practice.* New York: Chapman and Hall.

U.S. Bureau of the Census. *Construction Statistics Division*: "Average and Median Square Feet of Floor Area in New One-Family Houses Completed, by Region, 1971-1991."

U.S. Bureau of the Census. *Current Construction Report, Characteristics of New Housing, C25 Series.*

U.S. Bureau of the Census. *Current Construction Report, Residential Housing Permits, C40 Series.*

References (continued)

U.S. Department of Labor, Bureau of Labor Statistics. *Consumer Price Indexes for All Items, and for Fuels.*

Wright, Richard N., Arthur H. Rosenfeld, and Andrew J. Fowell. 1995. *Construction and Building: Federal Research and Development in Support of the U.S. Construction Industry.* Washington, DC: National Science and Technology Council.