Designation: E964 − 15

Standard Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Buildings and Building Systems[1]

This standard is issued under the fixed designation E964; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This is one in a series of practices for applying economic evaluation methods to building-related decisions. Methods covered by this practice are benefit-to-cost ratio (BCR) and savings-to-investment ratio (SIR). These are members of a family of economic evaluation methods that can be used to measure the economic consequences of a decision over a specified period of time. The BCR is used when the focus is on benefits (that is, advantages measured in dollars) relative to project costs. The SIR, a variation of the BCR, is used when the focus is on project savings (that is, cost reductions) relative to project costs. The family of methods includes, in addition to BCR and SIR, net benefits, net savings, life-cycle cost, internal rate-of-return, adjusted internal rate-of-return, and payback (see Practices E917, E1057, E1074, and E1121). Guide E1185 directs you to the appropriate method for a particular economic problem.

BCR and SIR are numerical ratios that indicate the economic performance of a project by the size of the ratio. A ratio less than 1.0 indicates a project that is uneconomic, a ratio of 1.0 indicates a project whose benefits or savings just equal its costs, and a ratio greater than 1.0 indicates a project that is economic. While it is straightforward to use ratios to determine whether a given project is economic or uneconomic, care must be taken to correctly interpret ratios when using them to choose among alternative designs and sizes of a project, or to assign priority to projects competing for limited funds.

1. Scope

1.1 This practice covers a procedure for calculating and interpreting benefit-to-cost ratios (BCR) and savings-to-investment ratios (SIR) as an aid for making building-related decisions.

1.2 A basic premise of the BCR and SIR methods is that future as well as present benefits and costs arising from a decision are important to that decision, and, if measurable in dollars, should be included in calculating the BCR and SIR.

1.3 Dollar amounts used to calculate BCR and SIR are all discounted, that is, expressed in time-equivalent dollars, either in present value or uniform annual value terms.

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E631 Terminology of Building Constructions

E833 Terminology of Building Economics

E917 Practice for Measuring Life-Cycle Costs of Buildings and Building Systems

E1057 Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems

E1074 Practice for Measuring Net Benefits and Net Savings for Investments in Buildings and Building Systems

E1121 Practice for Measuring Payback for Investments in Buildings and Building Systems

[1] This practice is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.81 on Building Economics.

Current edition approved May 1, 2015. Published June 2015. Originally approved in 1983. Last previous edition approved in 2010 as E964 – 06 (2010). DOI: 10.1520/E0964-15.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E1185 Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems
E1369 Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems
E1765 Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems
E1946 Practice for Measuring Cost Risk of Buildings and Building Systems and Other Constructed Projects
E2204 Guide for Summarizing the Economic Impacts of Building-Related Projects

2.2 *ASTM Adjuncts:*

Discount Factor Tables, Adjunct to Practices E917, E964, E1057, E1074, and E1121[3]

3. Terminology

3.1 *Definitions*—For definitions of general terms related to building construction used in this practice, refer to Terminology E631; and for general terms related to building economics, refer to Terminology E833.

4. Summary of Practice

4.1 This practice identifies related ASTM standards and adjuncts. It outlines the recommended steps for carrying out an analysis using the BCR or SIR method, explains each step, and gives examples. This practice discusses the importance of specifying objectives, alternatives, and constraints at the outset of an evaluation. It identifies data and assumptions needed for calculating BCRs and SIRs, and shows how to calculate the ratios. This practice emphasizes the importance of correctly interpreting the meaning of the ratios in different applications, and of taking into account uncertainty, unquantified effects, and funding constraints. It identifies requirements for documentation and recommends appropriate contents for a BCR or SIR report. This practice also explains and illustrates the application of the BCR and SIR methods to decide whether to accept or reject a project, how much to invest in a project, and how to allocate limited investment funds among competing uses.

5. Significance and Use

5.1 The BCR and SIR provide measures of economic performance in a single number that indicates whether a proposed building or building system is preferred over a mutually exclusive alternative that serves as the base for computing the ratio. It may be contrasted with the life-cycle cost (LCC) method that requires two LCC measures to evaluate the economic performance of a building or building system—one for each alternative.

5.2 The ratio indicates discounted dollar benefits (or savings) per dollar of discounted costs.

5.3 The BCR or SIR can be used to determine if a given building or building system is economic relative to the alternative of not having it.

[3] Available from ASTM International Headquarters. Order Adjunct No. ADJE091703.

5.4 The BCR or SIR computed on increments of benefits (or savings) and costs can be used to determine if one design or size of a building or system is more economic than another.

5.5 The BCR or SIR can be used as an aid to select the economically efficient set of projects among many competing for limited funding. The efficient set of projects will maximize aggregate net benefits or net savings obtainable for the budget.

6. Procedure

6.1 The recommended steps for carrying out an economic evaluation using the BCR or SIR method are summarized as follows:

6.1.1 Identify objectives, constraints, and alternatives (see Section 7),

6.1.2 Compile data and establish assumptions for the evaluation (see Section 8),

6.1.3 Compute BCR or SIR (see Section 9),

6.1.4 Analyze the BCR or SIR results and make a decision, taking into account uncertainty, unquantified effects, and funding or cash-flow constraints (see Section 10), and

6.1.5 Document the evaluation and prepare a report if needed (see Section 11).

7. Objectives, Constraints, and Alternatives

7.1 First, the decisionmaker's objectives should be clearly specified. This is crucial to defining the problem and determining the suitability of the BCR or SIR method. Second, constraints that limit potential alternatives for accomplishing the objectives should be identified. Third, alternatives that are technically and otherwise feasible in light of the constraints should be identified.

7.2 The example in this section illustrates the objective, constraints, and alternatives for a building investment that could be evaluated using the BCR method. The decisionmaker's objective is to maximize net benefits (profits) from investment in new stores in a national chain. The problem is to choose locations for the stores. There are two constraints: (*1*) the chain already has a sufficient number of stores in the northeast, and (*2*) there is only enough investment capital to open five stores. Twelve alternative locations (excluding locations in the northeast) are identified as potentially profitable. The BCR can help the decisionmaker identify which five of the twelve potential locations will maximize aggregate net benefits (profits) from the available budget. The approach is to compute a BCR for each location and rank the locations in descending order of their BCRs. If the budget cannot be fully allocated by selecting locations in descending order of their BCRs, the computation of aggregate net benefits is recommended to confirm that aggregate net benefits are maximized by the selected locations.

7.3 The example in this section describes the objective, constraints, and alternatives for a building investment that could be evaluated using the SIR method. The building is a jail. The objective is to reduce the cost of maintaining a target level of security (as might be measured by number of escapees per year). Constraints are that techniques to increase security must be unobtrusive to the surrounding neighborhood and must have low maintenance. The superintendent of prisons is evaluating with the SIR method a new perimeter detection device that costs 1 million dollars to install, and reduces labor costs for guards by 30 %. If the SIR is greater than 1.0, the device is deemed cost effective.

8. Data and Assumptions

8.1 Guidelines for compiling data and making assumptions are treated in detail in Practice E917, and therefore they are discussed only briefly here.

8.2 To calculate BCR or SIR, estimates typically are needed for revenue or other benefits; acquisition costs, including costs of planning, design, engineering, construction, purchase, installation, land, and site preparation; utility costs, including costs of energy, water, and sewage; nonenergy operating and maintenance costs; repair and replacement costs; resale or retention values; disposal costs; insurance costs; and, if applicable, functional use costs.

8.3 Information is also needed regarding the study period, discount rate, tax rates and applicable tax rules, and, if an integral part of the investment package, the terms of financing. (These topics are treated in Section 8 of Practice E917.)

8.4 The outcome of an analysis will vary, depending on the data estimates and assumptions. Thus, it is important to select carefully the assumed values for critical parameters to arrive at a realistic solution.

8.5 If the outcome appears particularly sensitive to the value assigned to a given parameter, and the estimate is of poor or unknown quality, the analyst may wish to improve the quality of the data. (Sensitivity analysis, a useful technique for identifying critical parameters, is treated in 10.3 of Practice E917.)

8.6 According to personal preference or organizational policy, the analyst normally adopts a simplified model of cash-flow timing to describe the occurrence of costs and benefits within each year; elects whether to express discounted amounts in present-value dollars or in annual-value dollars; and decides whether to work in constant dollars using a real discount rate or in current dollars using a nominal discount rate. (These topics are treated in Section 8 of Practice E917.)

8.7 The level of effort that goes into the evaluation may range from an inexpensive, back-of-the-envelope calculation intended to provide a ball-park estimate, to an expensive, detailed, thoroughly documented analysis intended to withstand scrutiny and to provide as much accuracy as possible. Different levels of effort are appropriate for different circumstances. (Factors influencing the level of effort are discussed in the paragraph on comprehensiveness in Section 8 of Practice E917.)

9. Calculation of BCR and SIR[4]

9.1 In concept, the BCR and SIR are simple: benefits (or savings) divided by costs, where all dollar amounts are discounted to present or annual values.

9.2 In practice, it is important to formulate the ratio so as to satisfy the investor's objective. This requires attention to the placement of costs in the numerator and denominator. To maximize net benefits from a designated expenditure, it is necessary to place in the denominator only that portion of costs on which the investor wishes to maximize returns. For example, to maximize the return on investor equity, place only that part of the investment budget representing investor's equity funds in the denominator of the ratio; deduct other costs from benefits or savings in the numerator. On the other hand, to maximize the return on the total of equity *and* borrowed investment funds, place their sum in the denominator of the ratio.

9.3 Formulation is important because changing the placement of cost and benefit items can induce changes in the ratio. Changing the placement of a cost item from the denominator (where it increases costs) to the numerator (where it decreases benefits or savings) will *not* cause a project that appears economic by one formulation of the ratio to appear uneconomic by a different formulation. But changes in the numerical value of the ratio can affect relative rankings of competing, independent projects, and thereby influence investment decisions.

9.4 Biasing effects, detrimental to economic efficiency, can result from certain formulations of the BCR and SIR ratios. For example, when allocating an investment budget among competing projects that differ significantly in their maintenance costs, placing maintenance costs in the denominator with investment costs tends to bias selection away from projects with relatively high maintenance costs, even when they offer higher net benefits (profits) than competing projects. Similar biasing effects can occur in the placement of other noninvestment costs such as energy or labor costs. This outcome reflects the fact that adding a given amount to the denominator of a ratio reduces the quotient more than does subtracting an identical amount from the numerator. Placing all noninvestment costs in the numerator will eliminate this bias when the objective is to maximize the return on the investment budget.

9.5 Eq 1 and 2 provide formulations of the BCR and SIR that avoid biasing effects, and allow the analyst flexibility in choosing the part of the investment budget on which to

[4] The NIST Building Life-Cycle Cost (BLCC) Computer Program helps users calculate measures of worth for buildings and building components that are consistent with ASTM standards. The program is downloadable from: http://www.eere.energy.gov/femp/information/download_blcc.html.

maximize the return. Eq 1 is used when benefits predominate, and Eq 2 when a project's primary advantage is lower costs.

$$BCR = \frac{\sum_{t=0}^{N} \left(B_t - \bar{C}_t\right)/(1+i)^t}{\sum_{t=0}^{N} \bar{I}_t/(1+i)^t} \quad (1)$$

where:

BCR = benefit-to-cost ratio,
B_t = benefits in period t; that is, advantages in revenue or performance, measured in dollars, of the building or system as compared with a mutually exclusive alternative (See Note 1),
$\bar{C}_t$ = costs in period t, excluding investment costs that are to be placed in the denominator for the building or system, less counterpart costs in period t for a mutually exclusive alternative,
$\bar{I}_t$ = those investment costs in period t on which the investor wishes to maximize the return, less similar investment costs in period t for a mutually exclusive alternative, and
i = the discount rate.

NOTE 1—Mutually exclusive alternatives are those for which accepting one automatically means not accepting the others. For a given project one mutually exclusive alternative may be not to undertake the project. If so, it is against this alternative that a potential investment must be compared to determine its cost-effectiveness. Alternative designs and sizes of a project for a given application are also mutually exclusive.

$$SIR = \frac{\sum_{t=0}^{N} S_t/(1+i)^t}{\sum_{t=0}^{N} \bar{I}_t/(1+i)^t} \quad (2)$$

where:

SIR = savings-to-investment ratio, and
S_t = cost savings in period t, adjusted to include any benefits in period t, for the building or building system to be evaluated as compared with a mtually exclusive alternate.

That is:

$$S_t = B_t - \bar{C}_t \; for \; t = 0, \ldots N$$

where:

$$\left|\sum_{t=0}^{N} \bar{C}_t\right| >> \sum_{t=0}^{N} B_t \text{ and } \sum_{t=0}^{N} \bar{C}_t < 0$$

NOTE 2—The BCR is normally used instead of the SIR unless cost reductions are *much* greater than revenue and performance advantages; hence the use of the symbol >> in the definition of S_t.

9.6 When financing is included in the analysis, I is typically set equal to investment costs paid up-front by the investor, that is, the downpayment paid out of equity funds. When financing is not included in the analysis, I is typically set equal to the total of investment costs.

9.7 Eq 3 is an alternative formulation of the BCR that gives the same mathematical results as Eq 1:

$$BCR = \frac{NB + \left(\sum_{t=0}^{N} \bar{I}_t/(1+i)^t\right)}{\sum_{t=0}^{N} \bar{I}_t/(1+i)^t} \quad (3)$$

where:

NB = net benefits, and

$$NB = \sum_{t=0}^{N} \left(B_t - \bar{C}_t - \bar{I}_t\right)/(1+i)^t$$

NOTE 3—Investors may prefer in some cases a formulation of the ratio that has a bias, as the term is used here, because they may wish to maximize the return on a particular type of fund. For example, current account expenditures might be the constraining resource, and they might wish to maximize the return on current account expenditures.

9.8 For ease of computation, instead of discounting the amount in each year and summing, as called for in Eq 1-3, the cash flows can be grouped into categories with the same pattern of occurrence and discounted using discount factors. (How to discount different patterns of cash flows is explained in the Section 9 of Practice E917.)

9.9 If income tax effects are a significant factor, they should be included in the analysis. (Income tax adjustments are treated in Section 9 of Practice E917 and are illustrated in Appendix X1 of this practice.)

10. Analysis of BCR or SIR Results and the Decision

10.1 Take care to interpret correctly the results of the BCR or SIR.

10.1.1 When a given, discretionary investment is compared against the alternative of doing nothing, a ratio greater than 1.0 indicates that the investment's benefits or savings exceed its costs. This supports accepting the investment on economic grounds, as opposed to doing nothing. For example, an SIR greater than 1.0 on an investment in a central vacuuming system for an office building indicates that the system is estimated to be cost effective. The higher the ratio, the more economically attractive the investment. (Accepting or rejecting individual investments is treated further in 12.2.)

10.1.2 When comparing alternative designs or sizes of a given building or building system, the alternative with the highest BCR or SIR is usually *not* the most economic choice. For design and sizing decisions it is important to compute incremental BCRs and SIRs by dividing the additional benefits or savings gained from an expansion in investment by the additional investment cost. It pays to expand an investment as long as incremental benefits or savings from the expansion exceed incremental costs. Net benefits (or net savings) reach their maximum when the incremental BCR or SIR equals 1.0. For example, if increasing the level of thermal insulation in a house from R-11 (resistance level = 11) to R-19 gives an incremental SIR of 5.0, the increment is cost effective. If further increasing the level of insulation from R-19 to R-30 gives an incremental SIR of 3.0, that increment is also cost effective. And, if increasing the insulation from R-30 to R-38 gives an incremental SIR greater than 1.0, it pays to expand the level to R-38. (Project design and sizing is treated further in 12.4.)

10.1.3 Using BCRs or SIRs to assign priority among independent, competing projects *suggests* the optimum selection, but is not always a reliable approach. If project costs are "lumpy" such that the budget cannot be used up exactly by adhering strictly to the BCR or SIR ranking, the optimum selection may differ from that indicated by the ratios. (Allocating a budget is treated further in 12.3.)

10.2 In the final investment decision, take into account not only the numerical values of the BCRs or SIRs, but also uncertainty of investment alternatives relative to the risk attitudes of the investor, the availability of funding and other cash-flow constraints, any unquantified effects attributable to the alternatives, and the possibility of noneconomic objectives. (These topics are discussed in Section 10 of Practice E917.)

10.2.1 Decision makers typically experience uncertainty about the correct values to use in establishing basic assumptions and in estimating future costs. Guide E1369 recommends techniques for treating uncertainty in parameter values in an economic evaluation. It also recommends techniques for evaluating the risk that a project will have a less favorable economic outcome than what is desired or expected. Practice E1946 establishes a procedure for measuring cost risk for buildings and building systems, using the Monte Carlo simulation technique as described in Guide E1369. Practice E917 provides direction on how to apply Monte Carlo simulation when performing economic evaluations of alternatives designed to mitigate the effects of natural and man-made hazards that occur infrequently but have significant consequences. Practice E917 contains a comprehensive example on the application of Monte Carlo simulation in evaluating the merits of alternative risk mitigation strategies for a prototypical data center.

10.2.2 Describe any significant effects that remain unquantified. Explain how these effects impact the recommended alternative. Refer to Practice E1765 for guidance on how to present unquantified effects along with the computed values of the BCR, SIR, or any other measures of economic performance.

11. BCR or SIR Report

11.1 A report should document the BCR or SIR analysis. Key data and assumptions should be identified for each of the alternatives considered. Significant effects that remain unquantified should be described in the report. And it should explain the basis for arriving at a decision. (This topic is discussed in more detail in Section 11 of Practice E917.)

11.2 Guide E2204 presents a generic format for reporting the results of a BCR or SIR analysis. It provides technical persons, analysts, and researchers a tool for communicating results in a condensed format to management and nontechnical persons. The generic format calls for a description of the significance of the project, the analysis strategy, a listing of data and assumptions, and a presentation of the computed values of the BCR, SIR, or any other measures of economic performance.

12. Applications

12.1 The BCR and SIR methods can be used to indicate whether a given investment is economically attractive, to choose among nonmutually exclusive projects competing for a limited budget, and to determine which engineering alternative (that is, which project design or size) is most economically efficient. This practice gives six illustrations of applications of the BCR and SIR methods. One is a detailed example of a real estate investment problem. It appears in Appendix X1. Another is a detailed example of savings resulting from energy efficiency improvements in a high school building. It appears in Appendix X2. The other four are brief illustrations presented in Tables 1-5.

12.2 *Accepting or Rejecting Individual Investments:*

12.2.1 If an investment's BCR or SIR is greater than 1.0, its discounted benefits or savings exceed its discounted costs, and it is economically attractive. On the other hand, if the ratio is less than 1.0, discounted benefits or savings are less than discounted costs, and it is not economically attractive.

12.2.2 An illustration of the application of the BCR method to decide whether to accept an investment in real estate is given in Appendix X1. The example shows the evaluation of an investment in an apartment building. It is an after-tax evaluation, and shows year-by-year cash flows. The BCR of 5.36 means that the real estate investment is estimated to return $5.36 for every dollar invested, over and above the minimum required rate of return imposed by the discount rate.

12.2.3 Table 1 illustrates the application of the SIR method to evaluate three energy conservation projects. Evaluated independently of one another, each project is cost effective as indicated in Column 7 by SIRs greater than 1.0.

12.3 *Choosing Among Nonmutually Exclusive Projects Competing for a Limited Budget:*

12.3.1 A second use of the BCR or SIR is to choose among nonmutually exclusive projects competing for a limited budget. If there were no budget constraint, it would pay to accept all projects whose discounted benefits or savings exceed their discounted costs. With a budget constraint, it may not be possible to accept all economically worthwhile projects, and a method of choosing among them is needed.

12.3.2 If the available budget can be fully exhausted by selecting projects in descending order of their BCRs or SIRs,

TABLE 1 Illustration of SIR to Evaluate Project Cost Effectiveness

(1)Projects	(2) Investment Costs, PV $[A]	(3) Energy Savings, PV $[A]	(4) Maintenance Cost, PV $[A]	(5) Savings Less Future Costs, PV $[A] (5) = (3) − (4)	(6) Net Savings, PV $[A] (6) = (5) − (2)	(7) SIR[B]
A	1000	6000	2300	3700	2700	3.70
B	1000	3800	0	3800	2800	3.80
C	1000	3000	−600	3600	2600	3.60

[A] PV $ = present value dollars.
[B] Calculated according to Eq 2; for example, for project alternative A, SIR = ($6000 − $2300) ⁄ $1000 = 3.70.

TABLE 2 Illustration of SIR Ranking

(1) Project	(2) Investment Costs, PV $[A]	(3) Savings, PV $[A]	(4) Net Savings, PV $[A] (4) = (3) – (2)	(5) SIR	(6) SIR Ranking
A	10 000	8 500	–1500	0.85	6
B	30 000	33 220	3220	1.11	3
C	5 000	6 660	1660	1.33	1
D	40 000	42 550	2550	1.06	5
E	90 000	96 250	6250	1.07	4
F	10 000	12 620	2620	1.26	2
G	45 000	49 840	4840	1.11	3

[A] PV $ = present value dollars.

TABLE 3 Project Data

(1) Project Size Alternatives	(2) Total Investment Required, $	(3) Project Life, years	(4) Total Benefits, $	(5) Net Benefits, $
0	0	0	0	0
A	100 000	20	500 000	400 000
B	125 000	20	575 000	450 000
C	145 000	20	600 000	455 000
D	155 000	20	605 000	450 000

TABLE 4 BCRs for Project Size Changes[A]

(1) From Size	(2)	(3)	(4) To Size	(5)	(6)
	0	A	B	C	D
0	. . .	5.0	4.6	4.1	3.9
A	. . .	. . .	3.0	2.2	1.9
B	. . .	. . .	. . .	1.3	1.0
C	. . .	. . .	. . .	. . .	0.5

[A] Based on data in Table 3.

the BCR or SIR method will provide a reliable guide for selecting projects. But if "lumpiness" in project costs precludes selecting projects exactly in descending order of their BCRs or SIRs, the BCR or SIR can be used only as an indicator of potential economic combinations of projects. In this case, potential combinations must be tested on a trial-and-error basis to determine which combination maximizes aggregate net benefits or net savings.

12.3.3 Table 2 illustrates the use of the SIR by a public agency to choose among potential investments in energy conservation. Seven independent projects (A through G) for different buildings are listed with their corresponding savings and costs. Column 6 ranks the projects by their SIR values.

12.3.4 To maximize net savings, the agency will undertake projects in descending order of their SIRs until the budget is exhausted. For example, if the budget were $90 000, Projects C, F, G, and B would be selected. No other combination of projects for that budget could produce a greater net savings.

12.3.5 If the SIRs fall below 1.0 before the available budget is exhausted, then project acceptance should terminate with the last project whose SIR exceeds 1.0. For example, a budget of $230 000 or more would allow accepting all projects in Table 2 except Project A which has an SIR less than 1.0. Project A is not cost effective and would be rejected even if the budget were sufficiently large to fund it.

12.3.6 If a higher-ranked project costs more than the available budget while lower-ranked projects are still affordable within the available budget, it may pay to skip over the higher-ranked project and select lower-ranked projects with ratios greater than 1.0 until the budget is exhausted. Alternatively, it may pay to drop projects already selected rather than pass over a project to take lower-ranked projects.

12.3.7 When the budget cannot be completely exhausted by strictly following the ratio ranking, it is sound practice to test different combinations of projects on a trial-and-error basis until the combination is found for which aggregate net benefits or net savings are maximized for the given budget. This may involve holding back part of the budget if it cannot be spent in such a way that aggregate net benefits or net savings increase with its expenditure.

NOTE 4—In evaluating multiple projects, the problem of interdependency among projects may arise; that is, undertaking one project may affect the relative life-cycle costs and savings of remaining projects. For example, the value of adding an automatic environmental control system will be different depending on the level of insulation in the building envelope and vice versa. Undertaking one will tend to diminish the value of the other. A simultaneous solution would be ideal.

A practical approach often used to approximate the combination of interdependent projects that maximizes aggregate net benefits or net savings is to evaluate each of the candidate projects independently of one another, select the one with the highest BCR or SIR, and then adjust the BCR or SIR on any remaining projects that are expected to be substantially altered by the first, higher-priority selection. The selection process can then be continued, with necessary adjustments to the BCRs or SIRs of all projects, as each additional selection is made. The need to find optimal combinations of interdependent projects may arise even if there is no budget constraint.

12.4 *Selecting Among Alternative Engineering Alternatives:*

12.4.1 A third application of the BCR or SIR method is to determine which project size or design is most efficient (that is, which engineering alternative maximizes net benefits or net savings). Determination of a dam's height and capacity is an example of sizing. Selecting among single, double, or triple glazing is an example of choosing the appropriate design.

12.4.2 If there is no budget limitation for a given project, the most efficient size or design occurs when the ratio of incremental benefits or savings to incremental costs equals (or approximates) 1.0 for the last unit of investment (that is, when marginal benefits equal marginal costs).

12.4.3 Tables 3 and 4 together illustrate how project size can be selected on the basis of incremental BCR analysis. Table 3 presents five size alternatives (zero and A through D) for a project, and corresponding total costs, total benefits, and net benefits. An inspection of net benefits in Column 5 shows that Size C maximizes net benefits and, hence, is the economically efficient choice in the absence of a budget constraint. This provides the correct solution against which to compare the results of the incremental BCR analysis in Table 4.

12.4.4 Table 4 shows the BCRs for all possible size changes for the alternatives described in Table 3. Table 4 is read by row and from left to right. By comparing each size against a zero baseline, the top row gives, in effect, BCRs on total investment. Although Size A has the highest BCR (5), it is not the size that

TABLE 5 Allocating a Budget Among Projects of Alternative Size[A]

(1) Investment Alternative	(2) Investment Cost, PV $[B]	(3) Cumulative Investment, PV $[B]	(4) Energy Savings,[C] PV $[B]	(5) Net Savings (5) = (4) – (2), PV $[B]	(6) SIR (6) = (4)/(2)	(7) Ranking
Add R-8 insulation	400	400	5000	4600	12.5	1
Increase insulation from R-8 to R-19	250	650	1600	1350	6.4	2
Add storm windows on north side	800	1450	3200	2400	4.0	3
Increase insulation from R-19 to R-30	250	1700	600	350	2.4	4
Add solar water heater	1500	3200	3300	1800	2.2	5
Add storm windows on south side	800	4000	1200	400	1.5	6
Increase insulation from R-30 to R-38	200	4200	250	50	1.3	7
Replace furnace	2500	6700	2750	250	1.1	8

[A] This example is solely for the purpose of illustrating use of the SIR method for making decisions. The costs and savings data are purely hypothetical.
[B] PV $ = present value dollars.
[C] Based on a 15 year holding period for the building with no residual value.

gives the highest net benefits. (This may be confirmed by Table 3 which shows that net benefits from the project in Size C are $55 000 more than net benefits from the project in Size A.)

12.4.5 Subsequent rows of Table 4 give the incremental BCRs calculated on differences between project sizes other than zero. For example, the incremental BCR associated with expanding project size from A to B is 3.0; from A to C, 2.2 (see Note 5); from A to D, 1.9; and from B to C, 1.3. The last size increment (that is, from C to D) is not cost effective as indicated by the incremental BCR of 0.5. Size C is the last separable increment with an incremental BCR equal to or greater than 1.0. Thus, in the absence of a budget constraint, C is the size that maximizes net benefits.

NOTE 5—The calculation of BCR from A to C, for example, is:

$$(\$600\,000 - \$500\,000)/(\$145\,000 - \$100\,000) = 2.2.$$

12.5 *Allocating a Budget Among Projects of Variable Design and Size:*

12.5.1 Sizing and designing individual projects and selecting among them when the budget is limited often should be a joint decision. A practical approach is to set up design and sizing decisions when possible in the same context as the budget allocation decision. This can be done by constructing the problem in such a manner that deciding how much to spend on given projects and which projects to select occurs simultaneously.

12.5.2 Table 5 illustrates the approach for a home improvement firm that is showing a prospective customer the most efficient set of retrofit alternatives for energy conservation. Candidate retrofits are to insulate the attic, which is currently uninsulated, add storm windows, add a solar hot-water heater, and replace the furnace with a high efficiency unit. The insulation project is divided into four size increments: (*1*) add insulation to a level sufficient to achieve a resistance value of 8 (that is, R-8), (*2*) increase the level from R-8 to R-19, (*3*) increase the level from R-19 to R-30, and (*4*) increase the level from R-30 to R-38. The storm window project is divided into two separately fundable parts: (*1*) add storm windows on the north side, and (*2*) add them on the south side. Dividing the window project according to orientation of the windows makes sense because orientation affects the cost effectiveness of the investment. The options are arrayed in Table 5 in descending order of their SIRs. The SIRs are all incremental SIRs because they are computed on the smallest feasible unit of each project. With an unlimited budget, the homeowner is advised to approve all four retrofits in their largest investment sizes. But with a limited budget of say, $1500, the cost-effective combination of projects is to place R-19 insulation in the attic and install storm windows on the north side. Note that in selecting a level of insulation of R-19, a sizing decision is made. Investment costs for the combination selected total $1450, and savings, $9800. No other combination of projects within the budget provides savings as great as $9800. (The $50 of the budget unallocated is assumed to be invested at the rate of return available on the next best investment (that is, at the opportunity cost of capital as measured by the discount rate), and, therefore, adds nothing to net benefits.)

12.5.3 When taking a joint approach to designing, sizing, and selecting projects for a limited budget, it is important to define appropriately the budget in order to avoid under-designing and under-sizing individual projects. For example, the manager of a building who receives a series of annual budgets would likely under-design and under-size projects if he or she focused on maximizing the return to each individual budget. In contrast, a consultant called in to specify what is to be done in a one-time retrofit of a building for energy conservation appropriately focuses on a single budget.

12.5.4 A second-best approach, which tends towards over-designing and over-sizing when there is a budget constraint, is to design and size each project so that the incremental ratio is equal to 1.0 (that is, as though there is no budget constraint), and then select projects as before in descending order of BCRs or SIRs computed on total project costs and benefits until the budget is exhausted. This approach may be appropriate for allocating a series of related budgets.

13. Keywords

13.1 benefit-cost analysis; benefit-to-cost ratio; building economics; engineering economics; investment analysis; savings-to-investment ratio

APPENDIXES

(Nonmandatory Information)

X1. USING THE BCR TO EVALUATE A REAL ESTATE INVESTMENT: ILLUSTRATION

X1.1 *Problem Statement*—A realty partnership must decide whether or not to purchase an apartment building.

X1.2 *Objectives*—The partnership is seeking profitable real estate investments that will more than compensate for its estimated opportunity cost of 12 % after taxes, without increasing average risk of the investment portfolio.

X1.3 *Constraints*—The partnership has 2 million dollars on hand to invest. Its target holding period for property is five years.

X1.4 *Terms*—The price of the apartment building is 10 million dollars. The seller is willing to finance 80 % of the price over five years at an interest rate of 10 %, with uniform payments at the end of each year.

X1.5 *Alternatives Considered:*

X1.5.1 Purchase and operate the apartment house for 5 years and then sell it.

X1.5.2 Do not invest in the apartment house.

X1.6 *Data and Assumptions*—Data and assumptions needed to evaluate the decision are summarized in Table X1.1.

X1.7 *Selection of the BCR Method*—Although the net benefits and internal rate-of-return methods are more often used to evaluate real estate investments, the BCR can also be used to measure profitability. By formulating the BCR with equity funds (the downpayment) in the denominator, the ratio will measure the discounted proceeds per dollar of equity funds invested.

X1.8 *BCR Computation*—Tables X1.2-X1.6 show the year-by-year cash-flow analysis and the computation of present values. The illustration splits the benefits and costs into components, provides an after-tax analysis, and shows year-by-year cash flow. Table X1.7 shows the calculation of the BCR. The ratio is 5.36.

X1.9 *Decision*—A BCR value of 5.36 means that after-tax proceeds are estimated to be more than $5.00 for every dollar of equity funds invested, over and above the required 12 % after-tax rate of return. Hence, the investment appears attractive on economic grounds, and the decision is to accept it. Note that part of the positive economic performance is due to the favorable terms of financing and part to the building. Because the terms of financing are integral to the investment package, it is appropriate to include financing in this analysis.

TABLE X1.1 Data and Assumptions for Real Estate Example

Study period (investor's holding period), years	5
Discount rate, after taxes (includes estimated inflation rate), %	12
Inflation rate (annual rate of general price change), %	5
Investment cost data:	
Purchase price:	$10 000 000
Land	$2 500 000
Improvements	$7 500 000
Downpayment (20 % of purchase price)	$2 000 000
Loan (80 % of purchase price)	$8 000 000
Loan interest rate, %	10
Loan life, years	5
Yearly loan payment ($8 million loan amortized over 5 years at 10 %)	$2 110 400
Depreciation period, years	27.5
Depreciation amount (straight-line method) per year	$272 727
Income tax treatment of loan interest	fully deductible
Resale of building (net of selling costs) at the end of 5 years	$12 100 000
Operating costs:	
Yearly costs, initially including maintenance, energy, trash removal, insurance, real estate taxes, etc.	$1 200 000
Rental revenue:	
Initial yearly rent from residential tenants	$4 200 000
Initial yearly lease revenue from concessions	$500 000
Yearly rate of increase, %	8
Federal income tax rate, %	28
State income tax rate, %	4
Combined tax rate, %	30.9[A]

[A] Taking into account the deductibility of state tax from federal tax liability, the combined tax rate is calculated as 0.28 (1 – 0.04) + 0.04 = 0.309.

TABLE X1.2 Calculation of Financed Investment Costs After Tax Deductions for Interest, in Present Value Dollars

(1) Year	(2) Yearly Load Payment, current $	(3) Interest Payments,[A] current $	(4) Income Tax Rate	(5) Income Tax Reductions from Interest Deductions, current $ (5) = (3) × (4)	(6) After-Tax Loan Payment, current $ (6) = (2) − (5)	(7) SPV[B] Factor	(8) Financed Investment Costs After-Taxes, PV $[C] (8) = (6) × (7)
0	. . .	. . .	. . .	. . .	. . .	. . .	. . .
1	2 110 400	800 000	0.309	247 200	1 863 200	0.8929	1 663 651
2	2 110 400	668 960	0.309	206 709	1 903 691	0.7972	1 517 622
3	2 110 400	524 816	0.309	169 168	1 948 232	0.7118	1 386 752
4	2 110 400	366 258	0.309	113 174	1 997 226	0.6355	1 269 237
5	2 110 400	191 843	0.309	59 279	2 051 121	0.5674	1 163 806
			PV of Financed Investment Costs after Deductions for Loan Interest:				7 001 068

[A] Interest payment, $_t$ = remaining principal,$_t$ × interest rate, and remaining principal,$_t$ = remaining principal$_{t-1}$ − (loan payment − interest payment$_{t-1}$).
[B] SPV = Single present value (or worth) discount factor from "Discount Factor Tables," the Adjunct to Practice E917, based on a 12 % discount rate.
[C] PV $ = Present value dollars.

TABLE X1.3 Calculation of Income Tax Savings Due to Depreciation Write-Off, in Present Value Dollars

(1) Year	(2) Yearly Depreciation, current $[A]	(3) Combined Income Tax Rate	(4) Yearly Income Tax Savings Due to Depreciation Write-Off, current $ (4) = (2) × (3)	(5) SPV[B] Factor	(6) Income Tax Savings Due to Depreciation Write-Off, PV $[C] (6) = (4) × (5)
0	. . .	. . .	. . .	. . .	. . .
1	272 727	0.309	84 273	0.8929	75 247
2	272 727	0.309	84 273	0.7972	67 182
3	272 727	0.309	84 273	0.7118	59 985
4	272 727	0.309	84 273	0.6355	53 555
5	272 727	0.309	84 273	0.5674	47 817
			PV of Total Income Tax Savings Due to Depreciation Write-Off:		303 787

[A] Based on straight-line depreciation of $7.5 million in capital improvements over 27.5 years. The yearly depreciation is tied to historical costs and does not change with general price inflation. Because the amount is fixed in current dollars, inflation erodes the constant dollar value of the depreciation allowance.
[B] SPV = Single present value (or worth) discount factor from "Discount Factor Tables," the Adjunct to Practice E917, based on a 12 % discount rate.
[C] PV $ = present value dollars.

TABLE X1.4 Calculation of Operating Costs After Taxes, in Present Value Dollars

(1) Year	(2) Operating Costs (Base-Year Prices)	(3) Multiplier to Adjust for Yearly Rate of Price Increase	(4) Yearly Operating Cost, Current $ (4) = (2) × (3)	(5) Income Tax Rate	(6) Tax Reduction Due to Operating Cost Deductions, Current $ (6) = (4) × (5)	(7) Yearly Operating Costs After Taxes, Current $ (7) = (4) − (6)	(8) SPV Factor[A]	(9) Operating Costs After Taxes,[B] PV $ (9) = (7) × (8)
0	$1 200 000	. . .	. . .	. . .	. . .	. . .	. . .	. . .
1	$1 200 000	$(1 + 0.05)^1$	1 260 000	0.309	389 340	870 660	0.8929	777 412
2	$1 200 000	$(1 + 0.05)^2$	1 323 000	0.309	408 807	914 193	0.7972	728 795
3	$1 200 000	$(1 + 0.05)^3$	1 389 150	0.309	429 247	959 903	0.7118	683 259
4	$1 200 000	$(1 + 0.05)^4$	1 458 608	0.309	450 710	1 007 898	0.6355	640 519
5	$1 200 000	$(1 + 0.05)^5$	1 531 538	0.309	473 245	1 058 293	0.5674	600 475
					PV of Total Operating Costs After Taxes:			3 430 460

[A] SPV = single present value (or worth) discount factor from "Discount Factor Tables," the Adjunct to Practice E917, based on a 12 % discount rate.
[B] PV $ = present value dollars.

TABLE X1.5 Calculation of Resale Value Net of Capital Gains Tax, in Present Value Dollars

(1) Year	(2) Resale Value at End of 5 Years,[A] current $	(3) Book Value at End of 5 Years,[B] current $	(4) Capital Gain, current $ (4) = (2) − (3)	(5) Capital Gains Tax Rate	(6) Capital Gains Tax, current $ (6) = (4) × (5)	(7) Resale Value Net of Capital Gains Tax, current $ (7) = (2) − (6)	(8) SPV Factor[C]	(9) Resale Value Net of Capital Gains, PV $[D] (9) = (7) × (8)
5	12 100 000	8 636 365	3 463 635	0.309	1 070 263	11 029 737	0.5674	6 258 273

[A] Resale value has two components: land and building. Land resale is based on land costs appreciating 10 % per year over 5 years. Building resale is based on the building's value deteriorating over 5 years at a compound rate of 0.0333 of the initial cost per year to reflect the fact that an existing building under normal circumstances tends to be worth less than an identical new building. At the same time the remaining value of the building is assumed to appreciate at the rate of general price inflation. Thus, after 5 years the estimated resale value of the land in current dollars is $4 026 275 (that is, $2 500 000 × $(1 + 0.10)^5$), the estimated resale value of the building is $8 081 023 (that is, $7 500 000 × $(1 − 0.0333)^5$ $(1 + 0.05)^5$), and the total resale is $12 100 000, (that is, $4 026 275 + $8 081 023), rounded to the nearest hundred thousand dollars.

[B] Original book value of $10.0 million less 5 years of straight-line depreciation of the $7.5 million in capital improvements (that is, $10 000 000 − $1 363 636 = $8 636 365).

[C] SPV = single present value (or worth) discount factor from "Discount Factor Tables," the Adjunct to Practice E917, based on a 12 % discount rate.

[D] PV $ = present value dollars.

TABLE X1.6 Calculation of Revenue After Income Taxes, in Present Value Dollars

(1) Year	(2) Initial Yearly Rent in Base-Year Prices	(3) Initial Yearly Lease Revenues from Concessions in Base-Year Prices	(4) Total Yearly Revenue in Base-Year Prices	(5) Multiplier to Adjust for Yearly Rate of Price Increase	(6) Total Yearly Revenue, current $ (6) = (4) × (5)	(7) Combined Income Tax Rate	(8) Income Tax Increase Due to Revenue, current $ (8) = (6) × (7)	(9) Total Yearly Revenue After Income Taxes, current $ (9) = (6) − (8)	(10) SPV Factor[A]	(11) Revenues After Income Taxes, PV $[B] (11) = (9) × (10)
0	$4 200 000	$500 000	$4 700 000	. . .	. . .	. . .	. . .	. . .	. . .	. . .
1	$4 200 000	$500 000	$4 700 000	$(1 + 0.08)^1$	5 076 000	0.309	1 568 484	3 507 516	0.8929	3 131 861
2	$4 200 000	$500 000	$4 700 000	$(1 + 0.08)^2$	5 482 080	0.309	1 693 963	3 788 117	0.7972	3 019 887
3	$4 200 000	$500 000	$4 700 000	$(1 + 0.08)^3$	5 920 646	0.309	1 829 480	4 091 166	0.7118	2 912 092
4	$4 200 000	$500 000	$4 700 000	$(1 + 0.08)^4$	6 394 298	0.308	1 975 838	4 418 460	0.6355	2 807 931
5	$4 200 000	$500 000	$4 700 000	$(1 + 0.08)^5$	6 905 842	0.308	2 133 905	4 771 937	0.5674	2 707 597
								PV $ of Total Revenue:		14 579 368

[A] SPV = Single present value (or worth) discount factor from "Discount Factor Tables," the Adjunct to Practice E917.

[B] PV $ present value dollars.

TABLE X1.7 BCR Computed from After-Tax Revenues and Costs

(1) Revenue, PV $[A]	(2) Resale Value Net of Capital Gains Tax, PV $[A]	(3) Financed Investment Costs, PV $[A]	(4) Income Tax Savings Due to Depreciation Write-off, PV $[A]	(5) Operating Costs, PV $[A]	(6) Total Revenue Less Future Costs (Numerator of BCR), PV $[A] (6) = (1) + (2) − (3) + (4) − (5)	(7) Downpayment[B] (Denominator of BCR)	(8) BCR (8) = (6) ⁄ (7)
14 579 368	6 258 273	7 001 068	303 787	3 430 460	10 709 900	2 000 000	5.36

[A] PV $ = present value dollars.

[B] Investor's equity.

X2. USING SAVINGS-TO-INVESTMENT RATIO (SIR) TO EVALUATE ENERGY EFFICIENCY IMPROVEMENTS IN A HIGH SCHOOL BUILDING

X2.1 *Background*—A high school constructed in 2009 in the greater St. Louis, MO, metropolitan area is subjected to an economic analysis to determine if energy efficiency improvements would be cost effective. The community where the high school is located does not have an energy code requirement, so the 1999 Edition of the ASHRAE 90.1 Standard (**1**)[5] is used as the basis for all energy-related requirements associated with the base case building design. The alternative against which the base case is analyzed uses the 2007 Edition of the ASHRAE 90.1 Standard (**2**) as the basis for all energy-related requirements associated with its building design. The ASHRAE 90.1 1999 Edition is used as the base case because it is assumed to be "common practice" for building design requirements in states with no state-wide energy code (Kneifel, 2012) (**3**). The ASHRAE 90.1 2007 Edition is used as the alternative because it provided the most comprehensive energy-related design requirements when the school was constructed. In addition, information on a similar school design constructed in

[5] The boldface numbers in parentheses refer to a list of references at the end of this standard.

Louisville, KY, indicated that the ASHRAE 90.1 2007 Edition design option was cost effective vis-à-vis the ASHRAE 90.1 1999 Edition design option (**3**). Both localities are in the same climate zone and have similar heating degree day and cooling degree day requirements.

X2.2 *Data and Assumptions*—Table X2.1 summarizes key assumptions, data elements and data values for the high school building being analyzed. The two-story building has a floor area of 130 000 ft^2 (12 077 m^2). The length of the study period is 25 years, which is less than the service life of the building but long enough to reflect a typical local government planning horizon. The economic analysis uses a 3 % real discount rate (net of general inflation or deflation) to convert future dollar values to present values. Because a real discount rate is being used, all dollar-denominated annual recurring costs and other future costs are expressed in 2009 constant dollars (dollars of uniform purchasing power exclusive of general inflation or deflation). The initial investment cost estimates for the base case, ASHRAE 90.1 1999 Edition, and the alternative, ASHRAE 90.1 2007 Edition, are based on data from RS Means CostWorks (**4**). The timing and values for all maintenance, repair and replacement costs are based on data from Whitestone Research (**5**).

X2.2.1 *Investment Cost Data*—The investment cost data reported in Table X2.1 cover the initial investment cost, the residual value of the high school building at the end of the study period in year 25, the present value (PV) of the residual value, and the PV of replacement costs for energy-related system upgrades. The initial investment cost is already expressed in PV terms, so no discounting is required. The residual value at the end of the study period is a measure of the economic value of the remaining life of the building. The residual value in year 25 is discounted to a PV through use of a single present value (SPV) factor (ASTM Discount Factor Tables Adjunct). The PV of replacement costs for energy-related system upgrades is calculated by multiplying the

TABLE X2.1 Economic Evaluation of Energy Efficiency Improvements in a High School Building: Data and Assumptions

Data Element	Value
Floor Area	130 000 ft^2 (12 077 m^2)
Study Period	25 Years
Discount Rate	3 % (real)
Investment Cost Data	
Initial Investment Cost	
ASHRAE 90.1 1999 Edition	$15 922 252
ASHRAE 90.1 2007 Edition	$15 967 212
Residual Value (Year 25)	
ASHRAE 90.1 1999 Edition	$5 412 217
ASHRAE 90.1 2007 Edition	$5 422 416
PV Residual Value	
ASHRAE 90.1 1999 Edition	$2 584 905
ASHRAE 90.1 2007 Edition	$2 589 776
PV Replacement Costs for Energy-Related System Upgrades	
ASHRAE 90.1 1999 Edition	$366 257
ASHRAE 90.1 2007 Edition	$388 167
Energy Cost Data	
Electricity	
Electricity Unit Cost	6.96¢/kWh
Annual Electricity Cost	
ASHRAE 90.1 1999 Edition	$98 358
ASHRAE 90.1 2007 Edition	$84 515
Electricity UPV*	17.60
PV Electricity Cost	
ASHRAE 90.1 1999 Edition	$1 731 096
ASHRAE 90.1 2007 Edition	$1 487 459
Natural Gas	
Natural Gas Unit Cost	$10.80/$kft^3$ ($305.82/$m^3$)
Annual Natural Gas Cost	
ASHRAE 90.1 1999 Edition	$53 351
ASHRAE 90.1 2007 Edition	$53 144
Natural Gas UPV*	19.92
PV Natural Gas Cost	
ASHRAE 90.1 1999 Edition	$1 062 757
ASHRAE 90.1 2007 Edition	$1 058 629
PV Energy Cost	
ASHRAE 90.1 1999 Edition	$2 793 853
ASHRAE 90.1 2007 Edition	$2 546 088
Future Maintenance and Repair Cost Data	
PV Baseline Maintenance and Repair Costs	
ASHRAE 90.1 1999 Edition	$4 311 735
ASHRAE 90.1 2007 Edition	$4 311 735
PV Maintenance and Repair Costs for Energy-Related System Upgrades	
ASHRAE 90.1 1999 Edition	$1 152 319
ASHRAE 90.1 2007 Edition	$1 099 783

appropriate SPV factor based on the timing of each replacement item by the dollar value for each replacement item in that time period and summing over all time periods and all replacement items. All four sets of investment costs are separately tabulated for the base case, ASHRAE 90.1 1999 Edition, and the alternative, ASHRAE 90.1 2007 Edition.

X2.2.2 *Energy Cost Data*—The energy fuel types used in the building are natural gas for heating and electricity for cooling and lighting. Unit cost data for electricity and natural gas are based on values reported in (**3**). The product of the annual energy requirement for each fuel type and the unit cost for the fuel type equals the annual fuel cost in the first year. Although both electricity and natural gas are treated as annual expenditures, the rate at which their prices change fluctuates over time. These fluctuations are referred to as escalation rates. The escalation rates used in this analysis and the associated discount factors used to convert an annual stream of fuel costs to a PV are based on future fuel prices projected by the Energy Information Administration of the U.S. Department of Energy as reported in (**6**). The Modified Uniform Present Value (UPV*) factor for each fuel type is based on a 25-year study period; it is reported in Table X2.1 as 17.60 for electricity and 19.92 for natural gas. The UPV* factor is applied to the corresponding annual fuel cost to convert the annual fuel cost in the first year to a PV over the 25-year study period. The annual energy requirements for electricity and natural gas are based on simulations from the EnergyPlus software program (**7**) as reported in Kneifel (2011) (**8**) and Lippiatt et al. (2013) (**9**). The EnergyPlus software program takes into account the integrated design nature of a building's systems. Specifically, as the thermal integrity of the building envelope is improved, the load on the HVAC system is reduced. Thus, the capacity requirements for the HVAC system may be reduced. Consequently, some of the increased investment cost for improving the thermal integrity of the building envelope may be partially offset by reductions in HVAC system cost. All energy-related costs are separately tabulated for the base case, ASHRAE 90.1 1999 Edition, and the alternative, ASHRAE 90.1 2007 Edition.

X2.2.3 *Maintenance and Repair Cost Data*—The PV of maintenance and repair costs is broken into two categories. The first category, referred to as Baseline Maintenance and Repair Costs, corresponds to the basic building; these costs exclude all energy-related system upgrades and are independent of any energy-related system upgrades. The second category covers all Energy-Related System Upgrades maintenance and repair costs. The timing and values for each category of maintenance and repair costs, baseline and energy-related system upgrades, are based on data from Whitestone Research (**5**). All maintenance and repair costs are separately tabulated for the base case, ASHRAE 90.1 1999 Edition, and the alternative, ASHRAE 90.1 2007 Edition.

X2.3 *Savings-to-Investment Ratio (SIR) Calculation*—Tables X2.2-X2.5 provide the information needed to calculate the SIR for the ASHRAE 90.1 2007 design option. Table X2.6 shows the SIR calculation. All dollar values reported in Tables X2.2-X2.5 are expressed in PV. Tables X2.2 and X2.3 provide the basis for calculating the values that go into the numerator (savings) and denominator (investment) of the SIR. The columns in Tables X2.2 and X2.3 are numbered to better illustrate how the resultant values are calculated. Table X2.2 reports the values used to calculate PV Investment Cost for the base case and the alternative. Column 2 contains the initial investment cost, Column 3 contains the PV of all energy-related replacement costs, and Column 4 contains the PV of the residual value. Following the procedure laid out in the life-cycle cost standard (Practice E917), PV Investment Cost equals initial investment cost (Column 2) plus PV replacement costs (Column 3) minus PV residual value (Column 4). The resultant PV Investment Cost is $13 703 604 for the base case and $13 765 603 for the alternative. Note that PV investment cost for the alternative is greater than PV investment cost for the base case. This difference in investment costs between the alternative and the base case equals the PV Incremental Investment Cost associated with the alternative's energy efficiency improvements; it becomes the denominator of the SIR. Table X2.3 reports the values used to calculate PV Non-Investment Cost for the base case and the alternative. Column 2 contains PV energy cost, Column 3 contains the PV of the baseline maintenance and repair costs, and Column 4 contains the PV of maintenance and repair costs for energy-related system upgrades. Following the procedure laid out in the life-cycle cost standard, PV Non-Investment Cost equals PV energy cost (Column 2) plus PV of the baseline maintenance and repair costs (Column 3) plus PV of maintenance and repair costs for energy-related system upgrades (Column 4). The resultant PV Non-Investment Cost is $8 257 907 for the base case and $7 957 606 for the alternative. Note that PV non-investment cost for the alternative is less than PV non-investment cost for the base case. This difference in non-investment costs between the base case and the alternative equals the PV Cost Savings associated with the alternative's energy efficiency improvements; it becomes the numerator of the SIR. Table X2.4 provides the data needed to calculate PV Incremental Investment Cost, the denominator of the SIR. Column 1 of Table X2.4 contains the PV investment cost for the alternative; it is transferred from the appropriate row in Column 5 of Table X2.2. Column 2 of Table X2.4 contains the

TABLE X2.2 Economic Evaluation of Energy Efficiency Improvements in a High School Building: Calculation of Investment Costs

Energy-Related Design Option	Initial Investment Cost	Present Value Replacement Costs for Energy-Related System Upgrades	Present Value Residual Value	Present Value Investment Costs
(1)	(2)	(3)	(4)	(5) = (2) + (3) - (4)
ASHRAE 90.1 1999 Edition	$15 922 252	$366 257	$2 584 905	$13 703 604
ASHRAE 90.1 2007 Edition	$15 967 212	$388 167	$2 589 776	$13 765 603

TABLE X2.3 Economic Evaluation of Energy Efficiency Improvements in a High School Building: Calculation of Non-Investment Costs

Energy-Related Design Option	Present Value Energy Cost	Present Value Baseline Maintenance and Repair Costs	Present Value Maintenance and Repair Costs for Energy-Related System Upgrades	Present Value Non-Investment Costs
(1)	(2)	(3)	(4)	(5) = (2) + (3) + (4)
ASHRAE 90.1 1999 Edition	$2 793 853	$4 311 735	$1 152 319	$8 257 907
ASHRAE 90.1 2007 Edition	$2 546 088	$4 311 735	$1 099 783	$7 957 606

TABLE X2.4 Economic Evaluation of Energy Efficiency Improvements in a High School Building: Calculation of Incremental Investment Cost

Present Value Investment Cost Alternative	Present Value Investment Cost Base Case	Present Value Incremental Investment Cost
(1)	(2)	(3) = (1) - (2)
$13 765 603	$13 703 604	$61 999

TABLE X2.5 Economic Evaluation of Energy Efficiency Improvements in a High School Building: Calculation of Cost Savings

Present Value Non-Investment Cost Base Case	Present Value Non-Investment Cost Alternative	Present Value Cost Savings
(1)	(2)	(3) = (1) - (2)
$8 257 907	$7 957 606	$300 301

TABLE X2.6 Economic Evaluation of Energy Efficiency Improvements in a High School Building: Calculation of Savings-to-Investment Ratio (SIR)

Present Value Cost Savings	Present Value Incremental Investment Cost	Savings-to-Investment Ratio (SIR)
(1)	(2)	(3) = (1)/(2)
$300 301	$61 999	4.84

PV investment cost for the base case; it is transferred from the appropriate row in Column 5 of Table X2.2. PV Incremental Investment Cost recorded in Column 3 of Table X2.4 equals Column 1 minus Column 2. The resultant value is $61 999. Table X2.5 provides the data needed to calculate PV Cost Savings, the numerator of the SIR. Column 1 of Table X2.5 contains the PV non-investment cost for the base case; it is transferred from the appropriate row in Column 5 of Table X2.3. Column 2 of Table X2.5 contains the PV non-investment cost for the alternative; it is transferred from the appropriate row in Column 5 of Table X2.3. PV Cost Savings recorded in Column 3 of Table X2.5 equals Column 1 minus Column 2. The resultant value is $300 301. The numerator of the SIR, PV Cost Savings, is entered in Column 1 of Table X2.6; the denominator of the SIR, PV Incremental Investment Cost, is entered in Column 2 of Table X2.6. The resultant value of 4.84 for the SIR, recorded in Column 3 of Table X2.6, equals Column 1 divided by Column 2.

X2.4 *Decision*—An SIR of 4.84 demonstrates that the additional investment in energy efficiency associated with the ASHRAE 90.1 2007 design option is cost effective. Recall that cost effectiveness only requires the SIR to be greater than 1.0 (see 12.2.1). Given that the energy-related system upgrades associated with the ASHRAE 90.1 2007 design option are focused on improving energy efficiency, it is instructive to also examine the PV of energy savings associated with the ASHRAE 90.1 2007 design option. Reference to Column 2 of Table X2.3 shows that the PV of energy costs for the base case is $2 793 853 whereas the PV of energy costs for the alternative is $2 546 088. Thus, the PV of energy savings associated with the alternative is $247 765, which translates into an 8.87 % energy cost savings. The magnitude of the PV of energy savings and the percent reduction in the PV of energy costs, in conjunction with the 4.84 SIR value, underscore the superior performance of the ASHRAE 90.1 2007 design option.

REFERENCES

(1) ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-1999 Standard-*Energy Standard for Buildings Except Low-Rise Residential Buildings*, ASHRAE, Inc., 1999 Edition

(2) ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2007 Standard-*Energy Standard for Buildings Except Low-Rise Residential Buildings*, ASHRAE, Inc., 2007 Edition

(3) Kneifel, J., *Prototype Commercial Buildings for Energy and Sustainability Assessment: Design Specification, Life-Cycle Costing and Carbon Assessment* (NIST Technical Note 1732), National Institute of Standards and Technology, Gaithersburg, MD, 2012.

(4) RS Means CostWorks Databases, http://www.rsmeans.com/.

(5) Towers, M., Dotz, R., and Romani, L., *The Whitestone Building Maintenance and Repair Cost Reference 2008-2009* 13th Annual Edition, Whitestone Research, Santa Barbara, CA 2008.

(6) Rushing, A., and Lippiatt, B., *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis* (NISTIR 85-3273-24), National Institute of Standards and Technology, Gaithersburg, MD, April 2009.

(7) EnergyPlus Example File Generator, Building Energy Simulation Web Interface for EnergyPlus, http://apps1.eere.energy.gov/buildings/energyplus/.

(8) Kneifel, J., *Prototype Commercial Buildings for Energy and Sustainability Assessment: Whole Building Energy Simulation Design* (NIST Technical Note 1716), National Institute of Standards and Technology, Gaithersburg, MD, 2011.

(9) Lippiatt, B., Kneifel, J., Lavappa, P., Suh, S., and Greig, A., *Building Industry Reporting and Design for Sustainability (BIRDS) Technical Manual and User Guide* (NIST Technical Note 1814), National Institute of Standards and Technology, Gaithersburg, MD, 2013.