Designation: E1185 – 15

Standard Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems[1]

This standard is issued under the fixed designation E1185; 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.

1. Scope

1.1 This guide identifies types of building design and building system decisions that require economic analysis and recommends ASTM practices, adjuncts, and computer programs that may be used to implement the appropriate economic methods for each decision type.

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
E964 Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for 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
E1369 Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems

2.2 *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 guide, refer to Terminology E631; and for general terms related to building economics, refer to Terminology E833.

4. Significance and Use

4.1 Standard practices for measuring the economic performance of investments in buildings and building systems have been published by ASTM. A computer program that produces economic measures consistent with these practices is available.[4] Discount Factor Tables has been published by ASTM to facilitate computing measures of performance for most of the practices.

4.2 This guide can be used to: (*1*) identify types of building design and system decisions that require economic analysis; (*2*) match the technically appropriate economic methods with the decisions; and (*3*) locate the methods in the ASTM practices and adjuncts listed in Section 2.

4.3 More than one method can be technically appropriate for many building decisions. Therefore the choice in practice of which technically appropriate economic method to use for evaluating a particular building decision will often depend on the perspective of the user. Some examples of factors that influence the user are: (*1*) ease of applying the methods, (*2*) level of familiarity of the user with the methods, (*3*) preference of the user for different methods, and (*4*) presence of budget limitations for the projects.

4.4 This guide identifies some features and limitations of the methods that might influence users' choices under varying conditions.

5. How to Use This Guide

5.1 Table 1 indicates which standard practices (that is, economic methods) are technically appropriate for the following four types of building investment decisions: acceptance/rejection, design, size, and priority.

5.1.1 In the context of this guide, an acceptance/rejection decision pertains to the cost effectiveness of an individual building or building system. This type of decision is made

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[1] This guide 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 Oct. 1, 2015. Published October 2015. Originally approved in 1987. Last previous edition approved in 2012 as E1185 – 12. DOI: 10.1520/E1185-15.

[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.

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

[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://energy.gov/eere/femp/building-life-cycle-cost-programs.

TABLE 1 Standard Practices For Making Building Decisions[A]

Type of Building Decision	Applicable Standards				
	LCC (Practice E917)	BCR (SIR) (Practice E964)	IRR (AIRR) (Practice E1057)	NB (NS) (Practice E1074)	PB (Practice E1121)
Acceptance or rejection	B	B	B	B	C
Design	B	D	D	B	E
Size	B	D	D	B	E
Priority or ranking	E	B	B	E	E

[A] All of the practices require discounting operations, but only Practice E917 explains discounting in detail. All of the methods can be applied using techniques for treating uncertainty and risk. Practice E917 discusses briefly some of these techniques. The other practices do not discuss them. Guide E1369 covers techniques for treating uncertainty in input variables to an economic analysis of a building investment project; it also recommends techniques for evaluating the risk that a project will have a less favorable economic outcome than what is desired or expected.
[B] Technically appropriate standard practice when total discounted benefits (savings) and costs are considered.
[C] Note limitations in Table 3.
[D] Technically appropriate standard practice when incremental discounted benefits (savings) and costs are considered.
[E] Not recommended.

independently of other project evaluations. It focuses on the merits of a single choice rather than on determining the most cost-effective design or size.

5.1.2 A design decision pertains to choices among competing designs for an individual building or building system, where only one design can be chosen.

5.1.3 A sizing decision pertains to choices among competing sizes or investment levels for an individual building or building system, where only one size or level can be chosen.

5.1.4 A ranking decision entails choosing one or more projects from a group of cost-effective projects when the available budget is not sufficient to fund them all.

5.1.5 Examine Table 1 to find which methods should be considered for a given decision. The ASTM designations are given in parentheses under the method names.

5.2 If there is any doubt as to which type of building decision shown in Table 1 best applies, consult the examples in Table 2. Table 2 lists examples for each of the four types of decisions shown in Table 1. Find in Table 2 a building decision similar to the one being analyzed, and select the corresponding decision type from Table 1. Section 6 contains illustrative cases of this process.

5.3 Once the type of decision has been identified and Table 1 has been consulted for the technically appropriate method, there will be several methods from which to choose. Note that while all of the methods that are marked as appropriate for a given decision will generally give answers that support the same decision (with the exception of payback), there are likely to be special considerations that make one or more methods preferred over the others. Examine the special considerations listed in Table 3 before making a final choice of methods.

5.4 Examine the practice(s) that corresponds to the chosen method(s). In the selected practice(s), read the sections on significance and use, applications, and limitations. If the practice(s) still seems appropriate, follow its procedures. If not, repeat the process using Tables 1 through 3 until an acceptable practice has been found or it has been determined that none of the practices is suitable for the decision at hand.

5.5 For assistance in calculating the measure(s) of economic performance provided by the selected method(s), use the adjunct and the Building Life-Cycle Cost Computer Program (BLCC).[4] The adjunct on Discount Factor Tables supports manual calculations for all of the methods. The BLCC supports computer calculations for all the methods except net benefits where revenues are involved and payback.

6. Illustrative Cases

6.1 Section 6 illustrates how to use this guide to choose the appropriate practice for each of the four types of building investment decisions listed in Table 2.

TABLE 2 Examples of Building Investment Decisions

Type of Building Decision	Examples
Acceptance or rejection	A.1 Is a water heater insulation kit cost effective? A.2 Are fire sprinklers cost effective? A.3 Is a given control system cost effective for managing HVAC equipment? A.4 Is a solar hot water system cost effective?
Design	D.1 Is single, double, or triple glazing most cost effective? D.2 What heating system is most cost effective? D.3 Which orientation of a building is most cost effective? D.4 Which code-approved plumbing system is most cost effective? D.5 Which wall type (for example, masonry, wood frame, curtain wall) is most cost effective? D.6 What floor finish (for example, carpeting, tile, wood) is most cost effective? D.7 What kind of insulation (for example, cellulose, fiberglass, rigid foam) is most cost effective? D.8 Is an item with low first costs more cost effective than a more durable substitute with higher first costs?
Size	S.1 What is the economically efficient level (*R* value) of insulation in the walls and above the ceiling of a house? S.2 How many square feet of collector area should be installed in a solar energy system? S.3 What heat pump efficiency (for example, HSPF 1.75, 2.0, 2.25) is most cost effective? S.4 What furnace efficiency (for example, AFUE 60 %, 75 %, 90 %) is most cost effective? S.5 What air conditioner efficiency (for example, SEER 7.0, 9.0, 11.0) is most cost effective?
Priority or ranking	P.1 What combination of investments in a given building (for example, new water heater, new floor tile, and new lighting system) is economically preferred when each is justifiable on economic grounds, but insufficient funds are available to pay for all of them?

TABLE 3 Special Considerations

Method	Unit Measure of Cost Effectiveness	Nature of Cash Flows	Limitations
LCC	$	primarily costs	A single LCC measure gives no indication of economic merit of a building or building component. LCC value for two or more alternatives are required for a LCC comparison. Alternatives being compared must be equivalent in other respects than LCC and must be compared over the same study period.
BCR (SIR)	dimensionless number	benefits (savings) and costs	Alternatives must be compared over the same study period unless replacement assets can be expected to repeat the costs and savings (benefits) of the original assets.
IRR (AIRR)	percent rate of return	benefits (savings) and costs	If the assumed rate of return on the reinvested earnings (savings) is not equal to the discount rate, then the IRR may yield inconsistent results with the BCR or SIR when ranking projects. Alternatives must be compared over the same study period unless replacement assets can be expected to repeat the costs and savings (benefits) of the original assets. The Unadjusted Internal Rate of Return method may give incorrect solutions and in some cases no unique solution.
NB (NS)	$	benefits (savings) and costs	Alternatives must be compared over the same study period.
PB	time (usually years)	benefits (savings) and costs	Cash flows beyond the payback period are ignored. The simple payback measure ignores the time value of money. Projects based on this criterion may not be cost effective.

6.2 *Acceptance or Rejection Decisions:*

6.2.1 If it is known (by recognition of the type of decision or by having examined examples in Table 2) that the building decision to be made is one of accepting or rejecting an individual project, then a choice must be made from the five practices listed in Table 1. To illustrate how such a choice might be made, an accept/reject building decision is evaluated in terms of the special considerations in Table 3.

6.2.2 An example of an accept/reject building decision is whether to install a programmable time clock to control heating, ventilating, and air conditioning (HVAC) equipment in a commercial building. The time clock would reduce electricity consumption by turning on only that part of the HVAC equipment that is needed during hours when the building is not occupied. Each of the five practices indicated in Table 1 for this type of decision is examined to see how useful it would be in assessing the cost effectiveness of the time clock.

6.2.3 The first method indicated in Table 1 is life-cycle cost (LCC). Life-cycle costs are the sum over a given study period of the costs of initial investment (less resale value), replacements, operations (including energy use), and maintenance and repair of an investment decision (expressed in present or annual value terms). Table 3 shows that the LCC method provides a dollar measure. Thus if decision makers want a dollar measure of cost effectiveness, LCC would meet that criterion. Table 3 also shows that the LCC method is most useful where cash flows are primarily costs. If the principal items affected by the time clock are increased capital costs for the time clock and reduced energy costs, then the LCC method would be appropriate.

6.2.3.1 To determine if the time clock is cost effective in accordance with the LCC method, the LCC of providing heating and cooling without the time clock would be compared against the LCC of heating and cooling with the time clock, where the costs of the time clock and its associated energy costs are included. On economic grounds, the time clock would be acceptable if its LCC were less than the LCC without it.

6.2.3.2 Note that the LCCs for each alternative (as discussed in limitations in Table 3) must be computed to make the LCC comparison. Note further that the two alternatives must be compared for the same period of time for the LCC comparison to be valid.

6.2.4 The second method indicated in Table 1 is the benefit-to-cost ratio (BCR) or savings-to-investment ratio (SIR). Table 3 shows this to be a dimensionless ratio of project benefits or savings to project costs. Benefits (savings) and costs are needed to calculate this ratio. In evaluating the time clock investment, the problem must be structured so that the energy cost reductions from having the time clock are expressed as benefits or savings and are compared against the associated increased capital cost. If the savings from the time clock exceed its associated costs (for example, if the SIR > 1.0), then the time clock is cost effective.

6.2.5 The third method in Table 1 is the internal rate of return (IRR). This is the only method in Table 3 that provides a rate-of-return measure in percentage terms. To use the IRR to evaluate the time clock investment, savings and cost data are needed. The IRR is that rate of interest that discounts the future stream of cash flows (net savings in this case) to a sum that just equals the investment cost of the time clock. If the IRR is greater than the minimum acceptable rate of return to the investor (MARR), then the time clock is cost effective.

NOTE 1—The Internal Rate of Return of Practice E1057 defines two IRR measures: the unadjusted IRR (UIRR) and the adjusted IRR (AIRR). The UIRR measure assumes that the net cash flows are reinvested at a rate equal to that earned on the original investment, whereas the AIRR measure assumes that the net cash flows are reinvested at a rate different from that earned on the original investment. The AIRR measure will support the same answer to a given building decision as the other methods listed in Table 1 for that type of building decision. The UIRR measure will not always support the same answer. In addition, the UIRR method sometimes yields multiple solutions and therefore gives no clear answer as to whether the time clock is cost effective.

6.2.6 The fourth method in Table 1 is net benefits (NB). If the benefits (savings) from the time clock exceed its cost, then NB > 0, and the time clock is cost effective.

6.2.7 The fifth method shown in Table 1 is payback (PB). It calculates the time to recover investment costs using benefits (savings) and cost data. PB for the time clock is the number of years required for savings from reduced energy costs to just equal the investment costs of the time clock. If PB (for example, three years) is equal to or less than the maximum acceptable payback period (for example, six years), the time clock will satisfy the payback criterion for acceptability. However, the limitations section of Table 3 indicates that PB is a misleading measure of cost effectiveness because it ignores cash flows beyond the payback year and, in the case of simple payback, it ignores the time value of money. Thus it is not a reliable measure of cost effectiveness when making accept/reject decisions.

6.2.8 The first four methods will agree on whether to accept the programmable time clock. The fifth method, PB, may or may not agree because of the shortcomings noted in 6.2.7.

6.3 *Design Decisions:*

6.3.1 The use of Table 3 in selecting the appropriate practice(s) for a design decision is illustrated by the choice of a heating system to be installed in a new building. The design choice is among a conventional oil furnace, a solar energy system (including an electrical resistance backup system), and a gas furnace.

6.3.2 Four methods are indicated in Table 1 to be technically appropriate for evaluating design decisions. The first is LCC. The LCC (including investment, maintenance, energy, and other related costs) for each of the three heating system design alternatives is calculated for a common study period and compared to see which system has the lowest LCC. The performance of the different systems must be the same in terms of thermal comfort for the comparison to be valid. The least costly system on a LCC basis would be the economically efficient choice.

6.3.3 The *D* used in Table 1 to indicate that BCR (SIR) measures can be used to evaluate design decisions means that incremental or marginal benefits (savings) and costs must be used in the calculations instead of total benefits (savings) and costs. This distinction is important because the use of totals in the calculations of BCR (SIR) will generally lead to economically inefficient design choices.

6.3.3.1 Pair-wise comparisons are needed to compute incremental SIRs. Let us assume that initial investment costs are lowest for the gas furnace, next lowest for the conventional oil system, and highest for the solar energy system. The heating system with the least first cost, the gas furnace, is considered the base case. The incremental investment costs of the oil furnace are the difference between investment costs of the gas furnace and of the oil furnace. Incremental savings are the difference between the present value of energy, maintenance, and other future net cash flows of the gas furnace and of the oil furnace. The ratio of incremental savings to incremental investment costs is the incremental SIR of the oil furnace. If the SIR > 1.0, then the oil furnace is preferred on economic grounds to the gas furnace. If the oil furnace SIR < 1.0, then the gas furnace is preferred. The preferred system becomes the base case against which the next alternative is then compared. For illustrative purposes, assume the oil furnace is more cost effective (oil furnace SIR > 1.0). The next step in the design decision is to make a pair-wise comparison of the oil furnace to the solar energy system. If the incremental SIR > 1.0 for the solar energy system, then it is the cost-effective choice. If the incremental SIR < 1.0 for the solar energy system, then the oil furnace is the cost-effective choice.

6.3.3.2 To make a valid economic comparison, the study period used in finding the present value of net cash flows must be the same for each of the alternative heating systems.

6.3.4 To determine which of the three heating systems is most cost effective using the IRR, the benefits (savings) and costs again must be analyzed incrementally. Thus the incremental IRR of the oil furnace, when compared to the gas furnace base case, is the interest rate that discounts the stream of differential future net cash flows between the two alternatives to just equal the extra investment cost of the oil furnace over the gas furnace. If the incremental IRR > MARR, then the oil furnace is more cost effective. On the other hand, if the IRR < MARR, then the gas furnace is more cost effective. The cost-effective system becomes the base case against which the next system is compared. Assuming the IRR > MARR, the next step would be to compute the incremental IRR of the solar energy system over the oil furnace to see which of those two systems would be more cost effective.

6.3.5 To determine which of the alternative heating systems is most cost effective using the NB method, net benefits are computed both for the oil furnace and for the solar energy system in comparison to the base case of a gas furnace. The alternative that yields the greatest NB is most cost effective. If NB are negative for the oil furnace and solar energy system, then the gas furnace is most cost effective.

6.3.6 The payback method is not recommended for design decisions because of the limitations cited in 6.2.7.

6.4 *Sizing Decisions:*

6.4.1 The use of Table 3 in selecting the appropriate standard practice(s) for a sizing decision is illustrated by the choice of insulation thickness for the exterior walls of a building. The *R* (thermal resistance) level of insulation is used here as the size index for two reasons. First, for any given type of insulation, the *R* value is an increasing function of insulation thickness. Second, insulation is packaged and sold by *R* values. An example of a sizing decision applicable to wall insulation is to choose one among the three following insulation *R* values: *R*13, *R*15, and *R*19.

6.4.2 Four methods are listed in Table 1 for making sizing decisions. To use the LCC method, total life-cycle costs (including both energy costs and insulation material and installation costs) are calculated for each *R* level of insulation. The *R* value with the least LCC will be the most cost-effective choice. Note in Table 3 that a limitation of the LCC method is that alternatives being compared on the basis of LCC must be equivalent in all other respects. This means that, in the comparisons of *R*-values, a prescribed degree of thermal comfort must be maintained in the building regardless of which *R* value is chosen.

6.4.3 The BCR (SIR) is listed in Table 1 as appropriate for sizing decisions when computed on an incremental basis. Starting with *R*13 as the base case size, the incremental SIR is computed for moving to *R*15. If that SIR > 1.0, the incremental SIR for moving from *R*15 to *R*19 is computed. Incremental SIRs are computed for successive *R* values until the SIR < 1.0.

The last R value with an incremental SIR > 1.0 is the most cost-effective insulation size.

NOTE 2—Increasing the size as long as the incremental SIR > 1.0 may not yield the most cost-effective choice, however, if the investment is characterized by one or more sharp increases in costs that are prerequisite to additional size expansion. For example, the increase in incremental costs to enlarge the wall cavity to accommodate an insulation thickness greater than $R13$ might be higher than the corresponding incremental benefits from moving to $R15$, the next increment of insulation. Yet, to move directly from $R13$ to $R19$, the combined costs from extra insulation and enlarging the wall cavity might be more than covered by corresponding incremental benefits. Thus $R19$ would be more cost effective than $R13$. Following the rule in 6.4.3 would lead under these circumstances to selecting $R13$, which is not the economically efficient choice. This problem in the use of incremental analysis for sizing also applies to incremental IRRs as described in 6.4.4.

6.4.4 To determine with the IRR which of the three insulation R values is most cost effective, again the savings and costs must be examined incrementally from one R value to the next. For example, the incremental IRR of increasing the R value from $R13$ to $R15$ is the interest rate that discounts the stream of differential energy savings between the two alternatives to just equal the extra investment cost of having $R15$ instead of $R13$. Any increase in the insulation level should be accepted as long as its incremental IRR > MARR.

6.4.5 The NB method can also be used to decide which of the three R values is most cost effective. The benefits (for example, energy cost reductions) and insulation costs are first determined for each R value relative to the base case of no insulation. Then net benefits are computed for each R value. The R value that yields the maximum NB is the most cost-effective choice.

6.5 *Ranking Decisions:*

6.5.1 When two or more projects are non-competing in the sense that selecting one does not preclude selecting any other, but there are insufficient funds to afford them all, the decision becomes which project or group of projects to choose. For example, if a new water heater, new floor tile, and new lighting system were all being considered in the remodeling of a commercial building, an economic analysis could be performed to determine which is (are) economically justified. If there were no budget constraint, then each project that met the acceptance criteria in 6.2.3 – 6.2.6 would be accepted. On the other hand, if there were a budget constraint which would not allow accepting all cost-effective projects, then some method for ranking and giving priority to eligible projects would be needed.

6.5.2 Table 1 indicates that BCR (SIR) or IRR can be used to rank projects. Assuming that the water heater, floor tile, and lighting are each economically justifiable, but that funding does not permit investing in all of them, the three projects would be funded in descending order of their SIRs or IRRs until the budget is exhausted. This procedure would indicate the one or more of the projects that together would maximize net benefits from the budgeted expenditure. Limitations of the SIR and IRR have been pointed out previously in this guide. The actual choice between the two methods depends to a great extent on whether the decision maker prefers to work with a percentage rate-of-return or with a dimensionless ratio.

7. Keywords

7.1 adjusted internal rate of return; benefit-cost analysis; building economic methods; budget limitation; cost effectiveness; design decision; economic analysis; life-cycle costing; net savings; payback; project evaluation; ranking; savings-to-investment ratio; uncertainty