



Designation: E 1057 – 06

Standard Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems¹

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INTRODUCTION

The internal rate-of-return (IRR) and adjusted internal rate-of-return (AIRR) methods are members of a family of economic evaluation methods that provide measures of economic performance of an investment over time. Other methods in this family of evaluation methods are life-cycle cost analysis, net benefits and net savings analysis, benefit-to-cost and savings-to-investment ratio analysis, and payback analysis.

The IRR and AIRR methods are the topic of a single standard practice because they both measure economic performance as a compound yield on investment. The IRR is the compound rate of interest that, when applied as a discount rate to a project's stream of dollar benefits and costs, will equate them. The AIRR is the overall yield taking into account earnings on receipts reinvested to the end of the study period. The IRR or AIRR is compared against the investor's minimum acceptable rate of return (MARR), and the investment is considered economically attractive if the calculated yield exceeds the MARR. If an investment entails an initial outlay and a single receipt at the end of the study period, there is no difference between the IRR and the AIRR. But if cash flows occur over multiple time periods, the two will normally be different. This arises because the AIRR includes in its measure the return on reinvestment of receipts, whereas the IRR does not.

The AIRR is recommended for most applications in which a measure of yield is desired. Caution is recommended in applying either measure, however, because problems arise under certain conditions.

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1. Scope

1.1 This practice covers a procedure for calculating and interpreting the internal rate of return (IRR) and adjusted internal rate of return (AIRR) measures in the evaluation of building designs, systems, and equipment.

2. Referenced Documents

2.1 ASTM Standards:²

- E 631 Terminology of Building Constructions
- E 833 Terminology of Building Economics
- E 917 Practice for Measuring Life-Cycle Costs of Buildings

and Building Systems

- E 964 Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Buildings and Building Systems
- E 1074 Practice for Measuring Net Benefits and Net Savings for Investments in Buildings and Building Systems
- E 1121 Practice for Measuring Payback for Investments in Buildings and Building Systems
- E 1185 Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems
- E 1369 Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems
- E 1765 Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems
- E 1946 Practice for Measuring Cost Risk of Buildings and Building Systems
- E 2204 Guide for Summarizing the Economic Impacts of Building-Related Projects

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.

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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.

2.2 ASTM Adjuncts:

Discount Factor Tables, Adjunct to Practices E 917, E 964, E 1057, E 1074, and E 1121³

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, refer to Terminologies E 631 and E 833.

4. Summary of Practice

4.1 This practice is organized as follows:

4.1.1 *Section 1, Scope*—Identifies coverage.

4.1.2 *Section 2, Applicable Documents*—Lists ASTM standards that are referenced.

4.1.3 *Section 3, Terminology*—Addresses definitions of terms.

4.1.4 *Section 4, Summary of Practice*—Outlines the contents.

4.1.5 *Section 5, Significance and Use*—Explains the relevance of the IRR and AIRR and indicates their appropriate uses.

4.1.6 *Section 6, Procedure*—Summarizes the steps in IRR and AIRR analysis.

4.1.7 *Section 7, Objectives, Constraints, and Alternatives*—Discusses the first step in an analysis, that is, the identification of the objectives of the analysis, any constraints that must be taken into account in finding a solution, and technically feasible project alternatives.

4.1.8 *Section 8, Data and Assumptions*—Discusses the second step in an analysis; that is the data and assumptions that are typically required for calculating the IRR and AIRR, and, in particular, the requirement of the AIRR for specification of a reinvestment rate.

4.1.9 *Section 9, IRR Calculation*—Describes the third step, performing calculations, as it applies to the IRR.

4.1.10 *Section 10, AIRR Calculation*—Describes the third step, performing calculations, as it applies to the AIRR.

4.1.11 *Section 11, Choosing Between the IRR and AIRR*—Discusses how to choose between the IRR and the AIRR.

4.1.12 *Section 12, Limitations*—Discusses limitations and shortcomings of the IRR and AIRR.

4.1.13 *Section 13, Analysis of IRR or AIRR Results and the Decision*—Discusses the decision criterion and the treatment of uncertainty, risk, and unqualified effects.

4.1.14 *Section 14, Applications*—Describes the types of decisions to which the IRR and AIRR are applicable.

4.1.15 *Section 15, Report*—Identifies information that shall be included in a report of an IRR or AIRR application.

5. Significance and Use

5.1 The IRR method has been used traditionally in finance and economics to measure the percentage yield on investment.

5.1.1 The IRR method is appropriate in most cases for evaluating whether a given building or building system will be economically efficient, that is, whether its time-adjusted benefits will exceed its time-adjusted costs over the period of

concern to the decision maker. However, it has deficiencies that limit its usefulness in choosing among projects competing for a limited budget.

5.2 The AIRR method is a measure of the overall rate of return that an investor can expect from an investment over a designated study period. It is appropriate both for evaluating whether a given building or building system will be economically efficient and for choosing among alternatives competing for a limited budget.

5.2.1 The AIRR method overcomes some, but not all, of the deficiencies of the IRR. The AIRR is particularly recommended over the IRR for allocating limited funding among competing projects.

6. Procedure

6.1 The recommended steps for applying the IRR or the AIRR method to an investment decision are summarized as follows:

6.1.1 Identify objectives, constraints, and alternatives.

6.1.2 Compile data and establish assumptions.

6.1.3 Compute IRR or AIRR based on a comparison of two alternatives (one of which may be to do nothing).

6.1.4 Compare the computed IRR or AIRR against the MARR to determine the acceptability of the alternative with the higher investment cost.

6.1.5 If a limited budget is to be allocated among competing alternatives, select alternatives in descending order of their IRR or AIRR measures until the budget is exhausted.

6.1.6 Report the results.

7. Objectives, Constraints, and Alternatives

7.1 Specify clearly the objective of the economic analysis.

7.1.1 Suppose, for example, an individual or organization has funds on hand to invest in real estate projects. The problem is which projects to choose from potential candidates. The objective of the economic analysis in this case is to identify the project or set of projects within the budget that is expected to maximize profits over the long run.

7.2 Identify any constraints that narrow the field of candidates.

7.2.1 Constraints, for example, might include a budget of \$1 000 000; a geographical limitation to buildings located within 100 km from downtown; and a strong preference for nonresidential property.

7.3 Identify feasible alternatives.

7.3.1 Feasible alternatives include an office building in the suburbs costing \$1 000 000; convenience shopping strips in nearby towns costing a total of \$900 000; two medical/dental offices costing \$500 000 each; and a \$1 000 000 investment share in a downtown shopping complex.

8. Data and Assumption

8.1 To calculate the IRR or AIRR, data are needed.

8.2 Benefit and cost data that are often relevant when calculating the IRR or AIRR are revenues, resale or salvage value, subsidies (for example, grants), and costs of planning, design, engineering, construction, purchase, installation, operation and maintenance, utilities, and repairs and replacement.

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

8.3 The time of occurrence of each benefit and cost is also needed.

8.4 Taxes such as tax credits, property taxes, and income taxes are also often relevant because they affect benefits and costs. If benefits and costs are adjusted for taxes, the IRR or AIRR measure gives the *after-tax* rate of return.

8.5 If the terms of financing are unique to each alternative, financing costs (and associated tax effects) should also be taken into account.

8.6 Choose a minimum acceptable rate of return (MARR) for comparison against the calculated IRR or AIRR.

8.6.1 The appropriate MARR indicates the investor's opportunity cost of foregoing the return on the next best investment opportunity in order to invest in the project in question.

8.7 If the AIRR is used, a reinvestment rate is needed.

8.7.1 The reinvestment rate is usually set equal to the MARR; hence, it equals the discount rate. This is because the reinvestment rate is an indicator of future opportunity cost, and that is also the purpose of the discount rate. Setting the reinvestment rate and the discount rate equal makes the reinvestment rate assumption in the AIRR method consistent with the reinvestment rate assumption that is implicit in the net benefits (net savings) method (Practice E 1074).

9. IRR Calculation

9.1 The IRR is the compound rate of interest that, when used to discount a project's cash flows, will reduce the present value of net benefits (PVNB) to zero. (See Practice E 1074 for a discussion of how to compute the PVNB.) The solution value of i^* in Eq 1 is the IRR. It is computed as a decimal, then expressed as a percent.

9.1.1 Find the value of i^* for which:

$$PVNB = \sum_{t=0}^N (B_t - \bar{C}_t)/(1 + i^*)^t = 0 \quad (1)$$

where:

PVNB = present value of net benefits (or, if applied to a cost-reducing investment, present value of net savings (PVNS)),

N = number of discounting periods in the study period,
 B_t = dollar value of benefits in period t for the building or system evaluated less the counterpart benefits in period t for the mutually exclusive alternative against which it is compared,

\bar{C}_t = dollar costs, including investment costs, in period t for the building or system evaluated less the counterpart costs in period t for the mutually exclusive alternative against which it is compared, and

i^* = interest rate for which PVNB = 0, that is, the IRR measure expressed as a decimal.

9.2 An algebraic solution of i^* is not possible with Eq 1 for all values of N . Use a computer program with built-in formulas to calculate IRR and AIRR. Or, use a manual approach to approximate the IRR such as the trial-and-error approach, the graphical approach, and an approach that uses simple payback and uniform present value (UPV) factor tables. (See Practice E 1121 for a description of payback and the Adjunct on Discount Factor Tables for UPV factors.)

9.2.1 Trial and Error Solution:

9.2.1.1 The trial-and-error approach to calculating the IRR entails choosing a trial rate of interest that is expected approximately to balance benefits and costs over the project study period. Then present value calculations are made for that trial rate. (For an illustration of discounting calculations, see Practice E 917.) If the PVNB is zero, then the trial rate is the solution value of the internal rate of return. If the PVNB is negative, the trial rate is too high, and a second, lower trial rate is then used. If the PVNB is positive for the original trial rate, then the IRR is higher than the trial rate, and a second, higher trial rate is used. When two trial rates are found such that one yields a PVNB greater than zero and the other a PVNB less than zero, the IRR lies between those rates and can be approximated by interpolation, provided the investment has a unique IRR. Considerable time is saved in the trial-and-error approach if the first trial rate is close to the true rate. One approach is to start with the MARR as the trial rate. If the PVNB is negative with the MARR, then the project is not economically feasible, and no further calculations are necessary. If the PVNB is positive, then select higher trial rates in an attempt to bound the true rate.

9.2.1.2 The UPV factor tables are useful in finding a trial rate. The first step is to sum the undiscounted cash flows (not including the initial cost) and divide the sum by the number of years in the study period (excluding any planning/design/construction period) to obtain an average annual cash flow. Then divide the initial project cost by the average to obtain a rough estimate of simple payback (SPB). The second step is to search the UPV discount factor tables in the row that corresponds to the study period for the UPV factor that is closest to the estimated SPB. (Again exclude any years in the planning/design/construction period.) The rate that appears at the top of the column in which the UPV factor is found is a promising trial rate. The more uniform the annual cash flow, the more likely that this trial rate will be close to the solution rate.

9.2.1.3 Table 1 illustrates the trial-and-error approach for calculating the IRR for an initial investment that yields an uneven yearly cash flow over four years. Columns 2 and 3 list the dollar values of benefits and costs that accrue in each of the four years, and Column 4 shows the net cash flow for each of those years, including the initial investment.

9.2.1.4 From inspecting Column 4 in Table 1, one might expect a relatively high return over four years. Using the approach described in 9.2.1.2 to select a trial rate, the calculated UPV value for four years corresponds in the Adjunct discount tables most closely to a rate of 25 %. Multiplying yearly net cash flows by single present value (SPV) factors for each year based on a 25 % discount rate (Column 5) converts them to equivalent present values (Column 6). Summing the values in Column 6 produces a PVNB of - \$415. Since the PVNB is less than zero, the IRR must be lower than the 25 % trial rate. Therefore another, lower rate is chosen, and the SPV factors for the lower rate are multiplied times yearly net cash flows. Using a second trial rate of 22 % (as illustrated in Columns 7 and 8) yields a positive PVNB of \$181. Therefore, the IRR must lie between 22 and 25 %. Linear interpolation yields an IRR of 22.9 % as follows:

TABLE 1 Trial-and-Error Solution for Internal Rate of Return

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Year (t)	Benefits (B _t)	Costs (C _t)	Net Cash Flow (B _t - C _t) (4) = (2) - (3)	SPV Factor for i = 25 %	PVNB at 25 % (6) = (4) × (5)	SPV Factor for i = 22 %	PVNB at 22 % (8) = (4) × (7)
0	0	\$10 000	\$-10 000	1.000	\$-10 000	1.000	\$-10 000
1	\$ 4 000	3 000	1 000	0.8000	800	0.8197	820
2	11 500	4 500	7 000	0.6400	4 480	0.6719	4 703
3	10 000	4 000	6 000	0.5126	3 076	0.5507	3 304
4	8 000	5 000	3 000	0.4096	1 229	0.4514	1 354
Total			\$7 000		\$-415		\$181

$$IRR = 22\% + \left(\frac{\$181 - \$0}{\$181 + \$415} \right) (25\% - 22\%) = 22.9\% \quad (2)$$

9.2.2 Graphical Solution:

9.2.2.1 Another approach to approximating the IRR is to use a graphical technique. The profile of the PVNB for a given investment is plotted for a range of discount rates. The IRR is approximately that rate where the PVNB curve intersects the discount rate axis, that is, where the PVNB is zero. Fig. 1 illustrates a graphical solution of the IRR for the project described in Table 2.

9.2.2.2 Given a discount rate of zero, the PVNB is the arithmetic sum of the net cash flows over time (that is, \$1300 for the project described in Table 2). Therefore the function intersects the vertical axis at \$1300. Using the discount rates labeled on the horizontal axis of Fig. 1 as trial rates, the PVNB values are calculated as shown in Table 2 and then plotted in Fig. 1.

9.2.2.3 An IRR of 27.2 % is found by visual inspection of the intersection of the profile of PVNB with the horizontal axis. Note that the graphical method usually approximates the solution IRR more closely than does the linear interpolation illustrated earlier with the trial-and-error approach, provided that enough PVNB points above and below the horizontal axis are plotted to form the curve accurately. However, if two trial rates are chosen very close to the true value, the linear interpolation approach can also approximate the true value closely.

9.2.3 Simple Payback-UPV Factor Table Solution:

9.2.3.1 A third technique for calculating the IRR works only when the annual net cash flows are constant or change at a constant rate. It works best if there is no planning/design/construction period. The procedure is first to compute simple payback (SPB). The next step is to search through the UPV or UPV* factors in the row corresponding to the study period for the factors that most closely bracket the value of the computed SPB. (UPV* factors, available in the adjunct on Discount Factors, are identified by an asterisk, indicating that annual net cash flows change at a constant rate.) Then see what discount rates those factors represent. Linear interpolation using the bracketing UPV or UPV* factors yields an approximation of the IRR. Note in this approach that the IRR is interpolated directly from the UPV or UPV* factor values; whereas, in the trial-and-error method described in 9.2.1, the IRR is interpolated from PVNB figures. In 9.2.1 the UPV tables are used only to find the first trial rate for calculating the PVNB.

9.2.3.2 Eq 3 shows how to calculate SPB, which is the first step in the procedure.

$$SPB = \frac{C_o}{(B - C)} \quad (3)$$

where:

- SPB = simple payback time,
- C_o = the initial project costs as of the base time, and
- (B - C) = constant annual net cash flow, or initial annual value of a net cash flow changing at a constant rate.

9.2.3.3 This approach is illustrated with the following problem. Find the IRR for a project with a one-time initial cost of \$1000 and benefits that accrue in a uniform stream of \$200 per year for 16 years. Dividing the one-time initial cost of \$1000 by the constant annual net cash flow of \$200 yields an SPB of 5. By searching through the row where N = 16 in the UPV columns of the adjunct factor tables, two UPV factors are found that most closely bracket the value 5. One factor is 5.162 for a discount rate of 18 %, and the other is 4.938 for a discount rate of 19 %. Having bracketed the IRR between 18 % and 19 %, a single value of 18.7 % is approximated through linear interpolation as follows:

$$IRR = 18\% + \frac{5.162 - 5.000}{5.162 - 4.938} (19\% - 18\%) = 18.7\% \quad (4)$$

10. AIRR Calculation

10.1 The solution value of \bar{i} in Eq 5 is the AIRR.

$$\sum_{t=0}^N \frac{(B_t - \hat{C}_t)(1+r)^{N-t}}{(1+\bar{i})^N} = \sum_{t=0}^N I_t/(1+r)^t \quad (5)$$

where:

- \hat{C}_t = dollar costs, excluding investment costs, in period t for the building or system evaluated less counterpart costs in period t for the mutually exclusive alternative against which it is compared,
- r = prescribed rate of return on reinvestment of cash flows,
- I_t = investment costs in period t on which return is to be maximized,
- \bar{i} = the interest rate that equates the two sides of the equation; that is, the AIRR measure expressed as a decimal, and
- B_t = is as previously defined.