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Standard Practice for
Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems[1]

This standard is issued under the fixed designation E1057; 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.

ε[1] NOTE—Adjunct title and stock number in 2.2 were updated editorially in April 2020.

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.

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.

1.2 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.

1.3 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
E631 Terminology of Building Constructions
E833 Terminology of Building Economics

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[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 Adjunct:*[3]

Discount Factor Tables - Adjunct to E917 Practice for Measuring Life-Cycle Costs of Buildings and Building Systems - Includes Excel and PDF Files

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 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

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[3] Available from ASTM International Headquarters. Order Adjunct No. ADJE091717-EA. Original adjunct produced in 1984. Adjunct last revised in 2003.

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.

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 E1074).

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 E1074 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:

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

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 E1121 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 E917.) 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:

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

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

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

(1) Year (t)	(2) Benefits (B_t)	(3) Costs ($\bar{C}_t$)	(4) Net Cash Flow ($B_t - \bar{C}_t$) (4) = (2) − (3)	(5) SPV Factor for $i = 25\%$	(6) PVNB at 25 % (6) = (4) × (5)	(7) SPV Factor for $i = 22\%$	(8) 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

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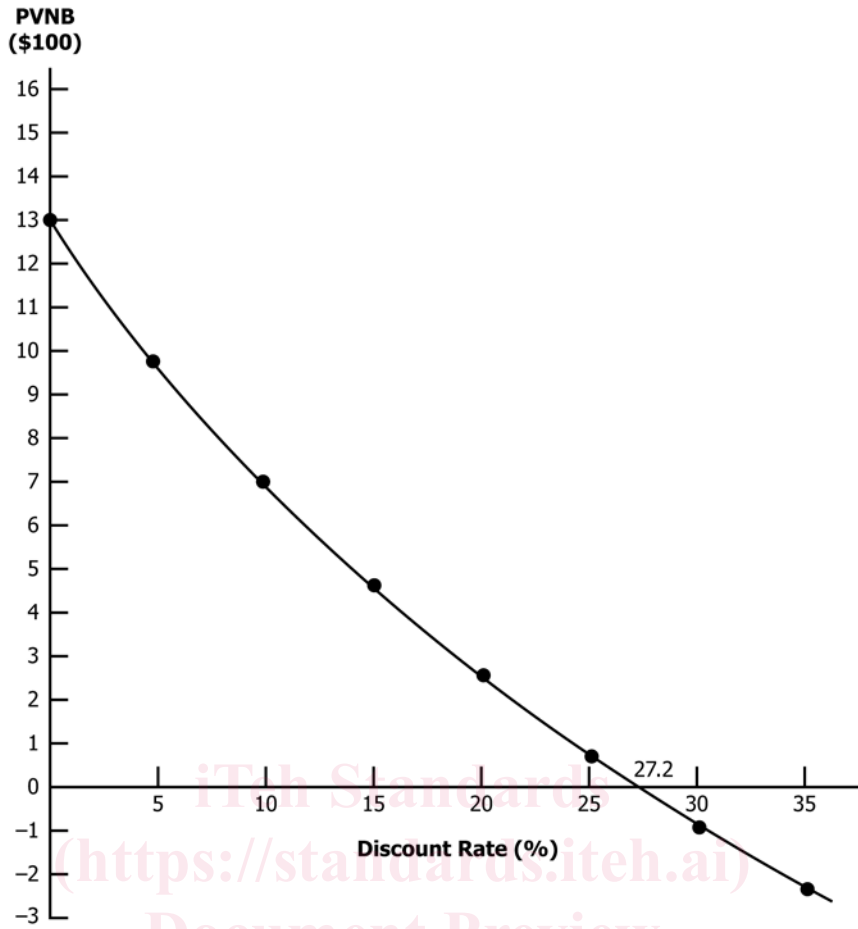
FIG. 1 Graphical Solution of IRR

TABLE 2 Data for Graphic Solution of IRR

Year (t)	Benefits (B_t)	Costs ($\hat{C}_t$)	Net Cash Flow ($B_t - \hat{C}_t$)	Trial Rates															
				5 %		10 %		15 %		20 %		25 %		30 %		35 %			
				SPV	PVNB	SPV	PVNB	SPV	PVNB	SPV	PVNB	SPV	PVNB	SPV^A	PVNB	SPV	PVNB		
0	0	$-2200	$-2200	1.000	$-2200	1.000	$-2200	1.000	$-2200	1.000	$-2200	1.000	$-2200	1.000	$-2200	1.000	$-2200		
1	$1000	0	1000	0.9524	952	0.9091	909	0.8696	870	0.8333	833	0.8000	800	0.7692	769	0.7407	741		
2	1500	0	1500	0.9070	1361	0.8264	1240	0.7561	1134	0.6944	1042	0.6400	960	0.5917	888	0.5487	823		
3	1000	0	1000	0.8638	864	0.7513	751	0.6575	658	0.5787	579	0.5126	513	0.4552	455	0.4064	406		
					$1300		$977		$700		$462		$254		$73		$-88		$-230

^{A} The SPV factors for 30 % and 35 % were calculated from the equation $SPV = \dfrac{1}{(1+i)^a}$ because factors for 30 % and 35 % were unavailable in the Adjunct discount factor tables.

19 %, a single value of 18.7 % is approximated through linear interpolation as follows:

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

10. AIRR Calculation

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

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

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,

$\bar{\iota}$ = 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.

10.2 Net cash flows $(B_t - \hat{C}_t)$ are carried forward (compounded) at the specified reinvestment rate (r) to the end of the study period (end of the Nth period) and summed. Future investment costs are discounted to present value using r as the discount rate. The value of i that discounts the resulting terminal value of net cash flows to a present value equal to present value investment costs is the AIRR.

10.3 The AIRR equals the IRR if the reinvestment rate, r, equals the IRR, that is, the solution value of i^*. If, however, r is less than i^*, the AIRR is less than the IRR; and if r is greater than i^*, the AIRR is greater than the IRR.[4]

10.4 The solution value of $\bar{\iota}$ in Eq 5, expressed as a decimal, is the AIRR. It can be solved for directly if the equation is rearranged as shown in Eq 6.

$$AIRR = -1.0 + (TV/PVI)^{1/N} \qquad (6)$$

where:

TV = $\sum_{t=0}^{N} (B_t - \hat{C}_t)(1+r)^{N-t}$, the terminal (future) value at the end of the study period of net cash flows excluding investment costs, and

PVI = $\sum_{t=0}^{N} I_t/(1+r)^t$, the present value of investment costs.

10.5 Once the TV and PVI are computed, the AIRR can be solved for directly by substituting TV, PVI, and N into Eq 6.

10.6 To illustrate the calculation of the AIRR, Eq 6 is used. In 9.2.2, an approximate IRR of 27.2 % was calculated for the investment data in Table 2. Now an AIRR is computed for the modified case where the reinvestment rate is lower than 27.2 %.

10.7 Table 3 illustrates the calculation of terminal values from a reinvestment of the first and second years' cash flow at 15 %. Note that net cash flows are identical to those for the investment described in Table 2.

10.8 The future value of $1000 earning 15 % for two years is $1323, the future value of $1500 earning 15 % for one year is $1725, and the future value of $1000 received at the end of

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[4] The National Institute of Standards and Technology 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.

TABLE 3 Calculation of Terminal Value

Year (t)	Net Cash Flow $(B_t - \bar{C}_t)$	Reinvestment Rate (r)	SCA Factor	Terminal Value
0	$−2200[A]			
1	1000	15 %	1.323	$1323
2	1500	15 %	1.150	1725
3	1000			1000
	$1300			$4048

[A] This is equal to PVI in Eq 6.

the final year is $1000. The terminal value (combined future values of the positive net cash flows) is $4048. Solving the problem in Table 3 using Eq 6 yields the following:

$$AIRR = -1.0 + \left(\frac{\$4,048}{\$2,200}\right)^{1/3} = 0.225 \text{ or } 22.5\% \qquad (7)$$

10.9 Eq 8, which is equivalent to Eq 6, can be used when the reinvestment rate is constant from year to year and the $PVNB$ and PVI have already been computed.

$$AIRR = -1.0 + (1+r)\left(1 + \frac{PVNB}{PVI}\right)^{1/N} \qquad (8)$$

10.9.1 Not having to derive the TV simplifies the calculation of the AIRR. (Note that r is a constant reinvestment rate and that the $PVNB$ and PVI have been computed with a discount rate equal to r.)

10.10 Eq 9 can be used when the reinvestment rate is constant from year to year and the savings-to-investment ratio (SIR) has already been computed (Practice E964). A comprehensive example linking the SIR method and the AIRR method applied to a building economics problem is provided in Appendix X1.

$$AIRR = -1.0 + (1+r)(SIR)^{1/N} \qquad (9)$$

10.11 The appropriate value of the reinvestment rate, r, is normally best approximated by the MARR, or discount rate, rather than the return on the original investment. Setting r higher than the discount rate suggests that the discount rate is too low, that is, it does not adequately reflect the next best investment opportunity. Setting r lower than the discount rate suggests that the discount rate is too high to reflect the next best investment opportunity. Thus, the discount rate is normally the appropriate value to substitute for r in using Eq 5, Eq 6, Eq 8, or Eq 9 to calculate the AIRR.

11. Choosing Between the IRR and AIRR

11.1 Controversy persists over whether the IRR or the AIRR is a more accurate measure of an investment's return. This controversy centers on how reinvested earnings over the study period are treated by the two methods. The IRR does not explicitly take into account the earnings on an investment's benefit stream or cash payouts during the study period. The AIRR does.

11.2 By incorporating the expected earnings of reinvested net cash flows, the AIRR provides a measure of the rate of return based on the investor's expected position at the end of the study period as compared with the initial position. The AIRR is a more accurate guide than the IRR for selecting that set of projects that will maximize aggregate PVNB over the study period.

11.3 For simple accept/reject decisions, either the IRR or the AIRR will generally suffice, except in cases where there is no unique value of the IRR. For most other decisions, the AIRR is more reliable than IRR for maximizing net benefits. (See Guide E1185 for types of decisions that require economic analysis and recommendations on which economic methods to use.)