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Standard Practice for Measuring Payback for Investments in Buildings and Building Systems[1]

This standard is issued under the fixed designation E 1121; 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—Section 2.2 was editorially corrected in January 2009.

1. Scope

1.1 This practice provides a recommended procedure for calculating and applying the payback method in evaluating building designs and building systems.

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
~~E1057Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems~~
E 1057 Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems
E 1074 Practice for Measuring Net Benefits and Net Savings for Investments in Buildings and Building Systems
E 1185 Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems

2.2 ~~*ASTM Adjuncts:*~~
~~Discount Factor Tables,Adjunct to Practice E917~~Adjuncts:
Discount Factor Tables Adjunct to Practices E 917, E 964, E 1057, E 1074, and E 1121[3]

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* 2, *Referenced Documents*—Lists ASTM standards and adjuncts referenced in this practice.

4.1.2 *Section* 3, *Definitions*—Addresses definitions of terms used in this practice.

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

4.1.4 *Section* 5, *Significance and Use*—Explains the significance and use of this practice.

4.1.5 *Section* 6, *Procedures*—Describes step-by-step the procedures for making economic evaluations of buildings.

4.1.6 *Section* 7, *Objectives, Alternatives, and Constraints*—Identifies and gives examples of objectives, alternatives, and constraints for a payback evaluation.

4.1.7 *Section* 8, *Data and Assumptions*—Identifies data needed and assumptions that may be required in a payback evaluation.

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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.

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

4.1.8 *Section* 9, *Compute Payback Period*—Presents alternative approaches for finding the payback period.

4.1.9 *Section* 10, *Applications*—Explains the circumstances for which the payback method is appropriate.

4.1.10 *Section* 11, *Limitations*—Discusses the limitations of the payback method.

5. Significance and Use

5.1 The payback method is part of a family of economic evaluation methods that provide measures of economic performance of an investment. Included in this family of evaluation methods are life-cycle costing, benefit-to-cost and savings-to-investment ratios, net benefits, and internal rates of return.

5.2 The payback method accounts for all monetary values associated with an investment up to the time at which cumulative net benefits, discounted to present value, just pay off initial investment costs.

5.3 Use the method to find if a project recovers its investment cost and other accrued costs within its service life or within a specified maximum acceptable payback period (MAPP) less than its service life. It is important to note that the decision to use the payback method should be made with care. (See Section 11 on Limitations.)

6. Procedures

6.1 The recommended steps for making an economic evaluation of buildings or building components are summarized as follows:

6.1.1 Identify objectives, alternatives, and constraints,

6.1.2 Select an economic evaluation method,

6.1.3 Compile data and establish assumptions,

6.1.4 Convert cash flows to a common time basis, and

6.1.5 Compute the economic measure and compare alternatives.

6.2 Only the step in 6.1.5, as applied to measuring payback, is examined in detail in this practice. For elaboration on the steps in 6.1.1-6.1.4, consult Practices E 964 and E 917, and Guide E 1185.

7. Objectives, Alternatives, and Constraints

7.1 Specify the kind of building decision to be made. Make explicit the objectives of the decision maker. And identify the alternative approaches for reaching the objectives and any constraints to reaching the objectives.

7.2 An example of a building investment problem that might be evaluated with the payback method is the installation of storm windows. The objective is to see if the costs of the storm windows are recovered within the MAPP. The alternatives are (*1*) to do nothing to the existing windows or (*2*) to install storm windows. One constraint might be limited available funds for purchasing the storm windows. If the payback period computed from expected energy savings and window investment costs is equal to or less than the specified MAPP, the investment is considered acceptable using this method.

7.3 Whereas the payback method is appropriate for solving the problem cited in 7.2, for certain kinds of economic problems, such as determining the economically efficient level of insulation, Practices E 917 and E 1074are the appropriate methods.

8. Data and Assumptions

8.1 Data needed to make payback calculations can be collected from published and unpublished sources, estimated, or assumed.

8.2 Both engineering data (for example, heating loads, equipment service life, and equipment efficiencies) and economic data (for example, tax rates, depreciation rates and periods, system costs, energy costs, discount rate, project life, price escalation rates, and financing costs) will be needed.

8.3 The economic measure of a project's worth varies considerably depending on the data and assumptions. Use sensitivity analysis to test the outcome for a range of the less certain values in order to identify the critical parameters.

9. Compute Payback Period

9.1 The payback method finds the length of time (usually specified in years) between the date of the initial project investment and the date when the present value of cumulative future earnings or savings, net of cumulative future costs, just equals the initial investment. This is called the payback period. When a zero discount rate is used, this result is referred to as the "simple" payback (SPB). The payback period can be determined mathematically, from present-value tables, or graphically.

9.2 *Mathematical Solution*:

9.2.1 To determine the payback period, find the minimum solution value of PB in Eq 1.

$$\sum_{t=1}^{PB} [(B_t - \bar{C}_t)/(1 + i)^t] = C_o \tag{1}$$

where:

B_t = dollar value of benefits (including earnings, cost reductions or savings, and resale values, if any, and adjusted for any tax effects) in period t for the building or system being evaluated less the counterpart benefits in period t for the mutually exclusive alternative against which it is being compared.

$\tilde{C}_t$ = dollar value of costs (excluding initial investment cost, but including operation, maintenance, and replacement costs, adjusted for any tax effects) in period t for the building or system being evaluated less the counterpart cost in period t for the mutually exclusive alternative against which it is being compared.

$B_t - \tilde{C}_t$ = net cash flows in year t,

C_o = initial project investment costs, as of the base time,

i = discount rate per time period t, and

$\frac{1}{(1+i)^t}$ = formula for determining the single present value factor,

NOTE 1— Eq 1 and all others that follow assume the convention of discounting from the end of the year. Cash flows are assumed to be spread evenly over the last year of payback so that partial year answers can be interpolated.

9.2.2 *Uniform Net Cash Flows*:

9.2.2.1 For the case where $(B_t - \tilde{C}_t)$ is the same from year to year, denoted by $(B - \tilde{C})$, the payback period (PB) corresponding to any discount rate (i) other than zero can be found using Eq 2.

$$PB = \frac{\log[1/(1 - (SPB \cdot i))]}{\log(1+i)} \tag{2}$$

where

$$SPB = C_o/(B - \tilde{C}). \tag{3}$$

When the discount rate is equal to zero,

$$PB = SPB \tag{4}$$

However PB is undefined when $(SPB \cdot i) \geq 1$; that is, the project will never pay for itself at that discount rate.

9.2.2.2 A calculation using Eq 2 is presented for the following investment problem. What would be the payback period for a project investment of \$12 000, earning uniform annual net cash flows of \$4500 for six years? A 10 % discount rate applies. First solve for the SPB: \$12 000/\$4500 = 2.6667. Eq 2 would yield the following:

$$PB = \frac{\log[1/(1 - (2.6667 \cdot 0.10))]}{\log 1.10} = (\log 1.3636/\log 1.1000) = (0.1347/0.0414) = 3.25$$

9.2.2.3 Since the payback period (3.25 years) is less than the six years over which the project earns constant net benefit returns, and since a shorter MAPP has not been specified, the project is considered acceptable.

9.2.3 *Unequal Net Cash Flows*:

9.2.3.1 For problems with unequal annual net cash flows, a common approach to calculating the payback period is to accumulate the present value of net cash flows year-by-year until the sum just equals or exceeds the original investment costs. The number of years required for the two to become equal is the payback period.

9.2.3.2 This approach is illustrated in Table 1. A project with seven years of unequal cash flows (Column 2) is evaluated at a discount rate of 12 %. The net cash flow in each year is discounted at 12 % to present value (Column 3). Each year's addition to the present value is accumulated in Column 4. The present value of net benefits (PVNB) in Column 6 is derived by subtracting the investment costs (Column 5) from the cumulative, discounted, future net cash flows (Column 4). The present value of net cash flows equals investment costs at some point in the fifth year. The payback period can be interpolated as follows:

$$PB = 4 \text{ years} + \frac{0 - (-\$3011)}{\$4933 - (-\$3011)} = 4.38$$

TABLE 1 Payback Problem With Unequal Annual Cash Flows

(1)	(2)	(3)	(4)	(5)	(6) = (4) – (5)
Years (t, s)	Net Cash Flows (\$) ($B_t - C_t$)	Discounted Net Cash Flows[A] (\$) $\left[\frac{B_t - \tilde{C}_t}{(1+i)^t}\right]$	Cumulative Discounted Net Cash Flows (\$) $\sum_{i=1}^{s}\left[\frac{B_t - \tilde{C}_t}{(1+i)^t}\right]$	Investment Cost (\$) (C_o)	Cumulative PVNB (\$) $\sum_{t=1}^{s}\left[\frac{B_t - \tilde{C}_t}{(1+i)^t}\right] - C_o$
0	0	0	0	50 000	–50 000
1	10 000	8 929	8 929		–41 071
2	20 000	15 944	24 873		–25 127
3	15 000	10 677	35 550		–14 450
4	18 000	11 439	46 989		–3 011
5	14 000	7 944	54 933		+4 933
6	12 000	6 080	61 013		+11 013
7	8 000	3 619	64 632		+14 632

[A] The discount rate = 12 %.

9.2.3.3 Since the payback period is less than the period over which the project earns positive net benefits (seven years), and since a shorter MAPP has not been specified, the project is considered acceptable.

9.2.4 *Net Cash Flows Escalating at a Constant Rate*:

9.2.4.1 To determine the payback period when net cash flows escalate at a constant rate, find the minimum solution of PB in Eq 5.

$$(B-\tilde{C})^{*}\sum_{t=1}^{PB}[(1+e)/(1+i)]^{t} = C_o \tag{5}$$

where:

$(B-\tilde{C})^{*}$ = initial value of an annual, uniformly escalating, net cash flow, and
e = constant price escalation rate per period t applicable to net cash flows.

9.2.4.2 When e is not equal to i, the payback period can be calculated by using Eq 6.

$$PB = \frac{\log[1+(SPB)(1-(1+i)/(1+e))]}{\log[(1+e)/(1+i)]} \tag{6}$$

where SPB = $C_o/(B-\tilde{C})^{*}$.

When e is equal to i,

$$PB = SPB \tag{7}$$

However PB is undefined and the project will never pay for itself at discount rate i if

$$SPB\ (1-(1+i)/(1+e)) \leq -1 \tag{8}$$

9.2.4.3 If the payback period is less than the period over which the project yields returns, the project is considered to be economically acceptable.

9.2.4.4 Eq 6 can be illustrated with the following problem. An energy conservation investment of \$40 000 yielding energy savings initially worth \$8000 annually is to be evaluated with an 8 % energy price escalation and a 12 % discount rate. Applying Eq 6 yields the following:

$$PB = \frac{\log[1+(\$40\,000/\$8000)(1-(1.12/1.08))]}{\log(1.08/1.12)}$$

$$= \frac{\log[1+5(-0.0370)]}{\log 0.9643}$$

$$= \frac{\log 0.8150}{\log 0.9643}$$

$$= 5.63 \text{ years}$$

9.3 *Estimating Payback Periods with Present-Value Tables*:

~~9.3.1Present-value tables, such as those found in *Discount Factor Tables*, Adjunct to Practice E917~~

9.3.1 Present-value tables, such as those found in Discount Factor Tables, can be used in certain cases to estimate payback periods without a calculator.

9.3.2 *Uniform Net Cash Flows*:

9.3.2.1 The payback period for a project with uniform annual net cash flows $(B-\tilde{C})$ can be estimated by first finding, in a table of Uniform Present Value (UPV) factors for the given discount rate, that UPV factor closest to the ratio of

$$\text{Initial Investment}/(B-\tilde{C})^{*} \tag{9}$$

The appropriate payback period is the number of periods (n) corresponding to that UPV factor. Interpolation can be used to more closely approximate the payback period.

9.3.2.2 As an example, when the discount rate is 12 %, the payback period for an initial investment of \$100 which returns \$15 per year is found as follows: The ratio of \$100/\$15 = 6.67. This ratio corresponds to a time period (n) of approximately 14.2 years in a table of Uniform Present Value factors based on a 12 % discount rate.

9.3.3 *Net Cash Flows Escalating at a Constant Rate*:

9.3.3.1 The payback period for a project with annual net cash flows escalating at a constant rate can be estimated by first finding, in a table of Modified Uniform Present Value (UPV*) factors for the given discount rate and escalation rates, that UPV* factor closest to the ratio of:

$$\text{Initial Investment}/(B-\tilde{C})^{*} \tag{10}$$

The appropriate payback period is the number of periods (n) corresponding to that UPV* factor. Interpolation can be used to more closely approximate the payback period.

9.3.3.2 As an example, when the discount rate is 12 %, the payback period for an investment of \$100 that returns net cash flows initially valued at $15 per year and increasing at 6 % per year is found as follows: The ratio of $100/$15 = 6.67. This ratio corresponds to a time period (n) of approximately 8.6 years in a table of Modified Uniform Present Value factors based on a 12 % discount rate and 6 % escalation.

9.4 *Graphical Solutions*:

9.4.1 The payback period for projects with uniform annual net cash flows or flows that increase at a constant rate can be found using graphs. The payback graphs described below present discounted payback as a function of SPB.

9.4.2 *Uniform Net Cash Flows*:

9.4.2.1 Fig. 1 plots payback periods up to ten years as a function of SPB values from zero to four years and discount rates from 1 to 25 %, in 2 % increments. Fig. 2 is similar to Fig. 1 except that payback periods are plotted for even values of the discount rate, 2 to 24 %. Figs. 3 and 4 are the same respectively as Figs. 1 and 2, except that SPB values range from 4 to 12 years and payback values range from 4 to 24 years. All of the curves are derived from Eq 2. The procedure for finding the discounted payback period is to solve first for SPB using Eq 3, and then to find the corresponding payback value on the curve for the given discount rate.

9.4.2.2 Taking the payback problem from 9.2.2.2, use the graphical approach to find the payback period for a $12 000 investment earning uniform annual net cash flows of $4500 for six years. Use 10 % discount rate. SPB is 2.7 (that is, $12 000 ÷ $4500). Therefore, use Fig. 2. Finding the value 2.7 on the horizontal SPB axis, draw a vertical line from that point to find its intersection with the payback curve for a discount rate of 10 %. Extending a line horizontally from that intersection to the vertical axis indicates a payback period of approximately 3.3 corresponding to the SPB value 2.7.

9.4.2.3 When the payback period is greater than the limit of the vertical axis, such as is the case for SPB = 9 and i = 11 % in Fig. 3, then the payback period cannot be read from the graph and must be computed from Eq 2.

9.4.2.4 Any project for which (SPB · i) ≥ 1 will have an undefined payback. That is, the project never pays off. For example, in Fig. 3, a project evaluated with SPB = 4.8 and a discount rate of 21 % would never pay off, and consequently the payback curve is truncated before it reaches a payback value corresponding to an SPB of 4.8 on the horizontal axis.

9.4.3 *Net Cash Flows Escalating At a Constant Rate*:

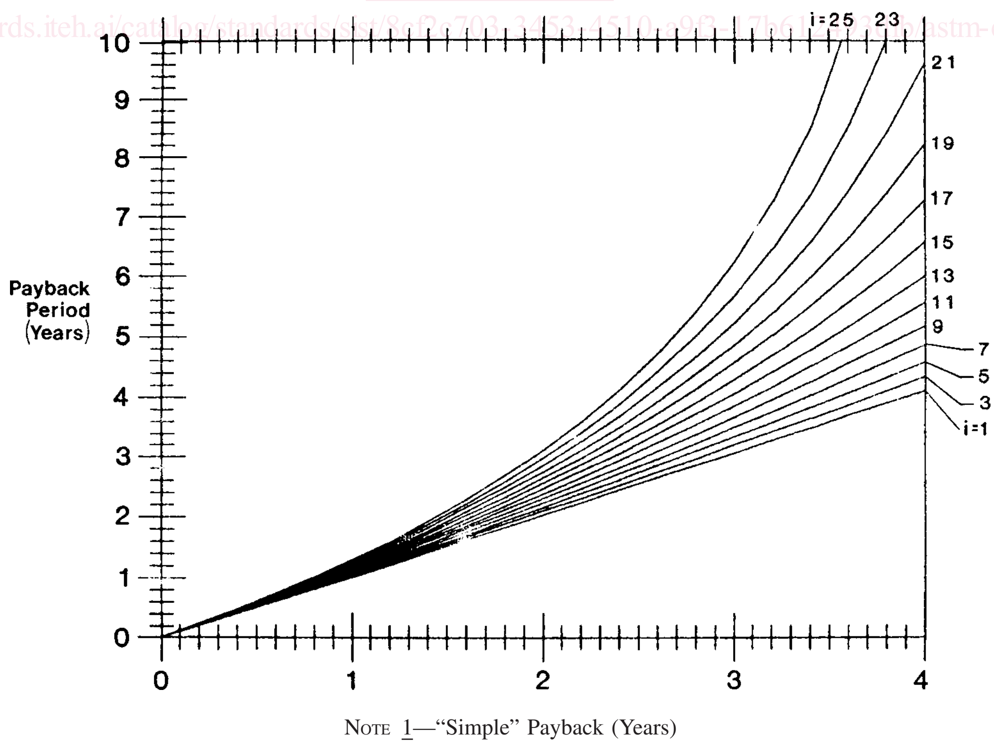
9.4.3.1 Figs. 5-8 present a family of payback curves plotted as a function of their k values,

where:

$$k = (1 + e)/(1 + i) \tag{11}$$

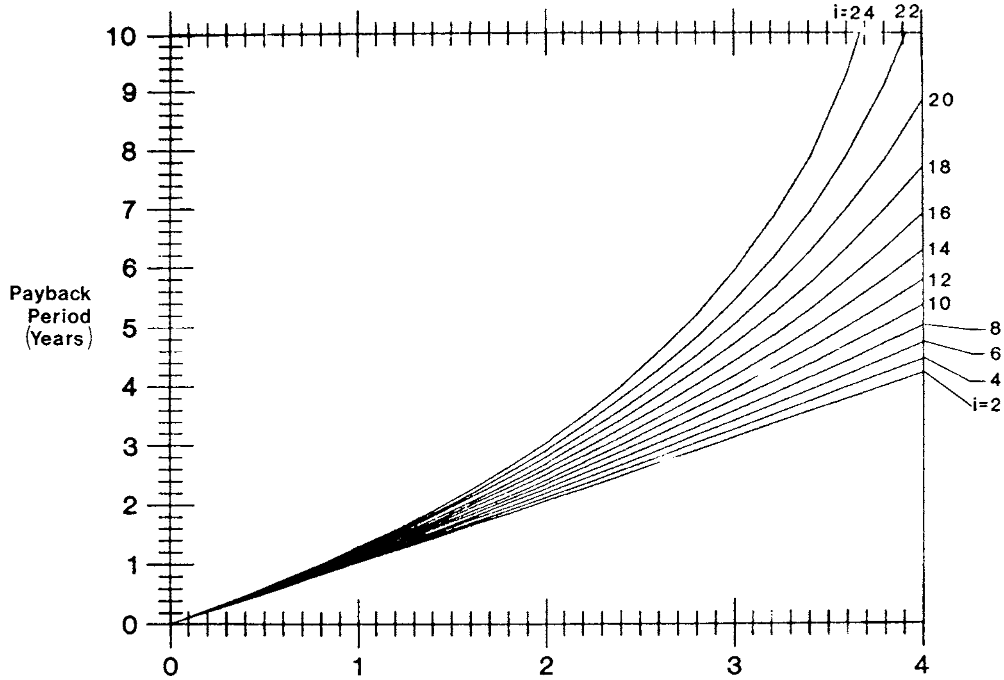
Each curve is derived from Eq 6. Figs. 5 and 6 present respectively payback periods corresponding to odd and even k values over the range k = 0.77 through 1.17, for SPB values up to four years. Figs. 7 and 8, respectively are the same as Figs. 5 and 6, except that SPB values range from four to twelve years, and k values have a lower bound of 0.81.

9.4.3.2 The major advantage of plotting payback periods for each value of k is that few graphs are required to describe many combinations of e and i. The use of Figs. 5 and 8 can be simplified by finding the value of k in Table 2, which provides a matrix



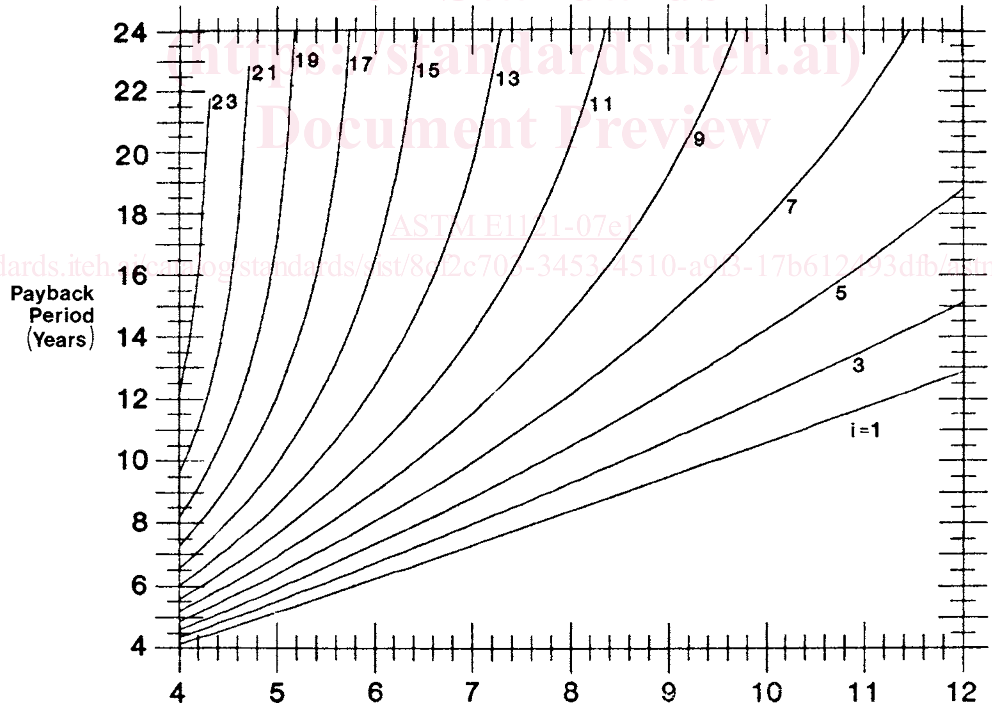
NOTE 1—"Simple" Payback (Years)

FIG. 1 Graphical Solution to Payback Period: SPB = 0 to 4 Years, *i* = 1 to 25 % (odd)



NOTE 1—"Simple" Payback (Years)

FIG. 2 Graphical Solution to Payback Period: SPB = 0 to 4 Years, *i* = 2 to 24 % (even)



NOTE 1—"Simple" Payback (Years)

FIG. 3 Graphical Solution to Payback Period: SPB = 4 to 12 Years, *i* = 1 to 23 % (odd)

of *k* values for all likely combinations of *e* and *i*.

9.4.3.3 Taking again the problem example from 9.2.4.4, the graphical approach is used to find the payback period for a $40 000 investment initially yielding annual energy savings of $8000, with an energy price escalation rate of 8 % and a discount rate of 12 %. Since SPB is 5 (that is, $40 000 ÷ $8000), it is known that the payback period will be found either in Fig. 7 or Fig. 8, which cover the SPB range of four to twelve years. By consulting the matrix of Table 2, we find a *k* value of 0.96 in the cell intersection for $e = 8$ and $i = 12$. Since the last digit of *k* is an even number, look to Fig. 8 (even) for the payback period corresponding to SPB = five years and $k = 0.96$. The answer is approximately 5.7.