

3.0 Life Cycle Costing

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3.1 Introduction

Life Cycle Costing (LCC) is a technique used to estimate the total costs of a project, installation or facility during the whole of its economic life, taking into account all costs and benefits. The use of LCC enables organisations to maximise the output value they generate for the available input resources. In the case of private enterprise, this means increasing profit – maximising the bottom line. In the case of public services, increased value means improving the quality and quantity of the services provided commensurate with the level of funding available.

In the context of electrical installation design, LCC is used to inform design choices. Usually, this means that all the costs, including investment cost, running costs and end-of-life costs, are compared for design options. Since the objective is to minimise the lifetime cost rather than to determine it, everything that remains the same for each design option can be ignored, simplifying the analysis and allowing greater focus on the differences.

This is a departure from the normal approach, in which the installation is designed to minimise initial cost with little regard to the future; an example might be the selection of a damper controlled ventilation system (which would be cheap to buy but very expensive to run) rather than, say, a variable speed fan, which would be more expensive to buy, but much cheaper to run.

In established facilities, the existing structures, operating procedures and technology already in use will determine the life cycle costs of many processes but, when new production lines or services are introduced or updated, or when additional facilities are constructed, there is an opportunity to specifically design the infrastructure using life cycle costing to achieve the lowest lifetime cost.

Often the focus on lifetime cost reveals that, because of the high cost of energy, the running costs are by far the greatest part of the total cost, meaning that the lowest life cycle cost design is one in which energy consumption has been carefully considered.

The advantage of LCC is obvious, so why is it so often ignored?

The first reason is that the benefit of LCC – primarily lower annual running costs – are an advantage to the operator of the facility, while the quick profit gained by installing the lowest price equipment is a benefit to the M&E contractor. Solving this issue requires the client – the building operator – to specify requirements to be met by the M&E contractor concerning operating costs.

Another reason is the perceived difficulty of assessing financial parameters, such as the cost of energy, discount rates, etc. for some time into the future. However, when LCC is used as a comparative tool to assess the relative costs of different design approaches, different equipment choices or different standards for installation practice, precise information is not needed – the objective is to determine, with a good degree of certainty, the lowest cost, rather than the exact cost. Performing a sensitivity analysis, by estimating the LCC for each option using a few values representing the predicted maxima and minima, improves confidence in the result.

A third perceived problem is that of dealing with risk in the project. Business decisions are always subject to change, perhaps due to changes in market conditions or technological advances leading to the installation becoming obsolete, so that it is sometimes difficult to define 'lifetime'. This concern, coupled with occasionally volatile economic conditions, led to the adoption of a rather conservative view of investment which required short payback times. This encouraged a 'lowest investment cost' approach, arguing that the smaller the sum invested, the easier it should be to recover and the lower the risk. Expressing all the costs in terms of their net present value (NPV) discounts future financial sums and reflects the possibility that the project may not be viable for as long as expected.

3.1.1 The Future Value of Money – Net Present Value

A sum of money which is to be paid or received some time in the future does not have the same value as the same sum of money today. This is because money available today could be invested to generate a profit or used to pay an outstanding debt but, since money is not available, it would need to be borrowed. A sum promised in the future cannot be committed and so has less value today. This is very relevant to the assessment of life cycle cost since costs and benefits that accrue in the later years would be given undue weight if they were included at full value.

The problem in assessing the lifetime cost is that the setting up costs occur at the beginning of the project while the costs of energy losses occur over a long period of time, so it is necessary to add together costs which arise, and have to be paid for, at different times. This is where the time value of money must be included in the calculation.

The simple addition of all future energy costs to the initial costs would be to imagine that sufficient money is to be put aside at the start of the project to pay all future bills or, put another way, that all future bills for energy costs would be paid in full at the start of the project.

This would not be an economical way to make provision for future payments and would unnecessarily inflate the total cost of the project. A more practical way would be to consider what the energy costs would be worth if the money were to be set aside to earn interest until the time came to pay each bill. It is evident that this procedure would require smaller amounts to be set aside.

It is common practice to express all costs and benefits in terms of 'Net Present Value' (NPV) at the start of the project using an appropriate 'discount rate'. The discount rate depends to a large extent on the cost of financing the business which will be determined by, for example, commercial interest rates and the cost of raising money from the markets, but it will also include an allowance for risk.

Allowing for risk can be complex. In a commercial building the risk may be low because the organisation is likely to continue to require the facility even though the business focus may change. In other areas, such as advanced technology, the risk may be very high; the development of practical electric vehicles requires many technological advances coupled with extensive infrastructure and behavioural changes which are not within the control of the vehicle developer and may not happen without timely policy initiatives. Higher perceived risk implies a higher discount rate.

The discount factor, r , to be applied to sums for a particular year, is given by:

$$r = \frac{1}{\left(1 + \frac{i}{100}\right)^n}$$

where:

- n is the number of years since the start
- i is the discount rate (%).

Table 8 below shows the annual discount factors for various discount rates over a period of 20 years.

Table 8 – Discount Factors for Various Discount Rates

Year	Discount Rate (%)									
	1	2	3	4	5	6	7	8	9	10
0	1	1	1	1	1	1	1	1	1	1
1	0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909
2	0.980	0.961	0.943	0.925	0.907	0.890	0.873	0.857	0.842	0.826
3	0.971	0.942	0.915	0.889	0.864	0.840	0.816	0.794	0.772	0.751
4	0.961	0.924	0.888	0.855	0.823	0.792	0.763	0.735	0.708	0.683
5	0.951	0.906	0.863	0.822	0.784	0.747	0.713	0.681	0.650	0.621
6	0.942	0.888	0.837	0.790	0.746	0.705	0.666	0.630	0.596	0.564
7	0.933	0.871	0.813	0.760	0.711	0.665	0.623	0.583	0.547	0.513
8	0.923	0.853	0.789	0.731	0.677	0.627	0.582	0.540	0.502	0.467
9	0.914	0.837	0.766	0.703	0.645	0.592	0.544	0.500	0.460	0.424
10	0.905	0.820	0.744	0.676	0.614	0.558	0.508	0.463	0.422	0.386
11	0.896	0.804	0.722	0.650	0.585	0.527	0.475	0.429	0.388	0.350
12	0.887	0.788	0.701	0.625	0.557	0.497	0.444	0.397	0.356	0.319
13	0.879	0.773	0.681	0.601	0.530	0.469	0.415	0.368	0.326	0.290
14	0.870	0.758	0.661	0.577	0.505	0.442	0.388	0.340	0.299	0.263
15	0.861	0.743	0.642	0.555	0.481	0.417	0.362	0.315	0.275	0.239
16	0.853	0.728	0.623	0.534	0.458	0.394	0.339	0.292	0.252	0.218
17	0.844	0.714	0.605	0.513	0.436	0.371	0.317	0.270	0.231	0.198
18	0.836	0.700	0.587	0.494	0.416	0.350	0.296	0.250	0.212	0.180
19	0.828	0.686	0.570	0.475	0.396	0.331	0.277	0.232	0.194	0.164

Energy prices are likely to increase over the lifetime of the project so the cost will increase each year by the factor:

$$1 + \frac{b}{100}$$

where b is the expected average percentage rate of increase of energy prices or, in the absence of information, the rate of general inflation, over the project lifetime.

It is also likely that the load carried by the busbar system will grow over the life of the installation and this must to be taken into account in two ways.

Firstly, the cost of energy in later years must be modified accordingly. Although load changes will occur at discrete (and unknown) points in the system lifetime, it is easier to assume that they occur at a uniform rate. The correction factor for each year is:

$$\left(1 + \frac{a}{100}\right)^2$$

where a is the average percentage increase in load current over the project lifetime.

Secondly, the system must be designed, from a safety point of view, to cope with the final load current which is given by

$$I_f = I_i \times \left(1 + \frac{a}{100}\right)^N$$

where:

- I_f is the load current at end of life
- I_i is the initial load current
- N is the circuit lifetime in years.

The overall correction factor, including discount rate, becomes:

$$r = \frac{\left(1 + \frac{a}{100}\right)^2 \times \left(1 + \frac{b}{100}\right)}{1 + \frac{i}{100}}$$

The NPV of the lifetime energy cost is therefore

$$NPV = C(r + r^2 + r^3 + \dots + r^{N-1} + r^N)$$

where:

- N is the project lifetime in years
- C is the first year cost

or

$$NPV = Cr(1 + r + r^2 + \dots + r^{N-2} + r^{N-1})$$

The term in parentheses in the equation above is a standard series so that

$$NPV = Cr \frac{(1 - r^N)}{(1 - r)}$$

and

$$NPV = CQ$$

where Q , the discount ratio, is given by

$$Q = r \frac{(1 - r^N)}{(1 - r)}$$

Note that if $r = 1$, the equation for Q cannot be evaluated, but from the original series it can be seen that in that case $Q = N$.

3.1.1.1 Monthly Payments

Electricity accounts are usually settled each month, even though agreements with regard to prices and financial matters may be made annually. In this case the following modifications to the derivation of the discounting factor Q may be appropriate. The difference in the value of NPV from that based on annual payments is small.

Define the monthly value of r as r_m where

$$r_m = \sqrt[12]{r}$$

Now, if the life of the project is N years, there will be $12N$ payments so the NPV is given by

$$NPV = C_m r_m (1 + r_m + r_m^2 + \dots + r_m^{12N-2} + r_m^{12N-1})$$

$$NPV = C_m r_m \frac{(1 - r_m^{12N})}{(1 - r_m)}$$

But since

$$r_m = \sqrt[12]{r}$$

then

$$NPV = C_m r_m \frac{(1 - r^N)}{(1 - r_m)}$$

and

$$Q_m = r_m \frac{(1 - r^N)}{(1 - r_m)}$$

Examples

For an installation with a projected life of 10 years and a discount rate of 5%, assuming 0% energy cost inflation and no load growth, paid annually,

$$r = \frac{1}{1.05} = 0.95238$$

$$Q = 0.95238 \times \frac{(0.38609)}{(0.04762)} = 7.7216$$

$$NPV = \text{First year energy cost} \times 7.7216$$

If paid monthly,

$$r_m = \sqrt[12]{0.95238} = 0.995942$$

$$Q_m = 0.995942 \times \frac{(1 - 0.95238^{10})}{1 - 0.995942} = 0.995942 \times \frac{0.38609}{0.004058} = 94.76$$

$$NPV = \text{First month energy cost} \times 94.76$$

For the same installation with a discount rate of 5%, energy price inflation of 3% and an average load current growth of 2%,

$$r = \frac{\left(1 + \frac{2}{100}\right)^2 \times \left(1 + \frac{3}{100}\right)}{1 + \frac{5}{100}}$$

$$r = \frac{(1.02)^2 \times 1.03}{1.05} = 1.020583$$

Note that $r > 1$.

$$Q = 1.020583 \times \frac{-0.29049}{-0.020583} = 14.4$$

$$NPV = \text{First year energy cost} \times 14.4$$

3.1.2 Loading

Few installations run at full load continuously. The maximum current must be used to select the initial conductor size and protective device rating but, for financial purposes, the rms average load must be used. This requires some knowledge about the load profile. To find the rms load, the profile is divided into a number of equal timeslots and the square of each current value calculated. The squares for all the time slots are summed, averaged and the root value calculated. The result is that current which, if it flowed continuously, would be equivalent to the actual load.

However, there is a problem with this method because the temperature of the busbar, and therefore the resistance, changes with current, meaning that energy losses for periods of low currents are overestimated, while those for periods of high current are underestimated. In practical terms the effect is small; firstly, the error is unlikely to shift the choice of bar size from one standard size to another and, secondly, for an optimised bar the current density is lower so the temperature rise, and therefore the variation, is much smaller.

Where the load profile is more complex, or there is a need for great accuracy, the suggested approach is to construct a straight line approximation of the load profile, calculate the energy loss at each current level and then determine the time average of the energy loss.

3.1.3 Lifetime

Lifetime can have several meanings. At the design stage, lifetime is the period for which the installation is expected to be needed to fulfil its original purpose. For a product line this may be quite short, while for a commercial building it will be rather longer. In practice, installations are often used for far longer because, for example, new products can be manufactured using the same installation, perhaps with small modifications. The useful lifetime is therefore longer than the initial 'economic' lifetime. The result is that the initial assessment – for the economic lifetime – gives a lower weight to running costs than would have been the case for the actual lifetime. It also delays the end-of-life so any benefit from recovering scrap conductor material is very heavily discounted so that it does not influence the financial decision.

3.1.4 Sensitivity Analysis

In most cases it will not be possible to accurately know all the data, for example, the design of the plant may not be finalised and future electricity costs cannot be determined accurately, so it is necessary to test the result to check how dependent the appraisal is on each variable and make an appropriate judgement.

3.2 Application to an Electrical Installation

Engineering design is always concerned with compromise within the boundaries of the design requirement. The functional requirements must be met, of course, but there are many ways of doing so; using more final circuits will provide more flexibility and better isolation for sensitive loads, while using larger conductor cross-sections will reduce energy losses and voltage drop resulting in lower energy losses and better dip resilience. Specifying energy efficient load equipment will reduce energy consumption. Each of these decisions has an impact on the future running costs of the installation in both energy and maintenance costs and an impact on the cost of the installation and its commissioning.

3.2.1 Installation Design

Many design decisions will be made based on the designer's experience of having done similar designs in the past and, for many parts of an installation, the 'business-as-usual' installation may also be the one with the lowest LCC because the base level is set by installation standards. For other areas there is an opportunity to reduce the LCC by optimising the design. For example:

1. Selecting energy efficient equipment will reduce energy costs. This includes, for example, transformers, motors, pumps and fans.
2. Considering energy efficiency when determining the conductor size for cables and busbars will reduce energy losses considerably in circuits feeding heavy loads. The 5% voltage drop at the load terminals, permitted by standards, represents an efficiency of only 95% - for a length of conductor! Unless the duty factor of the load is low, designing for a much lower voltage drop makes sense and reduces the LCC.
3. Designing for reliability by using separate dedicated circuits for sensitive equipment and heavy fluctuating loads and designing for reduced voltage drop in the installation to improve resilience against voltage disturbances will reduce downtime and maintenance costs, reducing the LCC.

The decisions made at the design stage determine the scale of the LCC, so this stage is extremely important – it is worth investing time in this process to reduce future costs.

3.2.2 Installation Costs

The installation costs include all the electrical design and installation costs for the project and, since they all occur at the start of the project, are therefore taken into account at full cost. When comparing the LCCs of different design options, only those elements that vary would need to be taken into account.

3.2.3 Recurring Costs

Recurring annual costs generally fall into two categories:

3.2.3.1 Maintenance Costs

All facilities require a certain amount of expenditure on maintenance. Reducing this requirement by, for example, designing for a lower working temperature to give a longer, more reliable life, or choosing lighting equipment with a long service life to reduce replacement frequencies, can significantly reduce costs.

3.2.3.2 Energy

Energy is expensive and the present upward trend is likely to continue making energy costs extremely important. In many industrial processes, energy cost accounts for the majority of the total lifetime cost, so measures taken to increase energy efficiency at the design stage are often extremely cost-effective. LCC provides a methodology to determine the economic optimum conductor size for a given loading and duty cycle.

However, designers must also consider voltage drop. Standard installation practice allows a maximum 5% voltage drop between the origin of the installation and the load terminals. In many cases, this condition will be met or exceeded by the conductor size corresponding to the economic optimum, but this cannot be assumed. For example, the economic optimum conductor size for a load with a low duty factor may be relatively small, but the conductor length may introduce an excessive voltage drop. The installation designer must take care to allocate the voltage drop 'budget' to the various parts of the installation and, because busbars tend to be used in the higher current parts of the system, they deserve greater attention. The voltage drop should always be checked once the economic optimum has been determined.

The questions that have to be answered are: what is the conductor size with the lowest LCC for a given circuit load, duty factor and lifetime, and is the voltage drop sufficiently low?

The following simple example calculates the total cost – conductor cost plus energy loss – for a simple single phase circuit using a range of cross-sections and a range of operating times. The circuit feeds a load of 500 A.

Table 9 lists the maximum working current for a range of vertically mounted busbars, assuming an ambient temperature of 35°C and a working temperature of 90°C, operating in free air. The material costs listed are based on a copper price of \$7500 per tonne.

Note that the current-carrying capacity of a bar is not proportional to the cross-sectional area (assuming the same ambient and working temperatures etc). This is because convection becomes less efficient for larger bars since the air cooling flowing up the face at the top of the bar has already been warmed as it flows up the bottom of the face. Consequently, the maximum busbar rating cannot be directly scaled although, since the difference is not very large, scaling can be used to estimate the starting point for calculation.

Table 9 – Maximum Working Current for a Range of Busbar Sizes

Width (mm)	Thickness (mm)	Area (mm ²)	Weight (kg)	Max Current (A)	Material Cost (€)
25	6.3	158	1.403	530	7.518
31.5	6.3	198	1.768	639	9.472
40	6.3	252	2.245	776	12.029
50	6.3	315	2.807	932	15.036
63	6.3	397	3.536	1127	18.945
80	6.3	504	4.491	1390	24.057
100	6.3	630	5.613	1662	30.071
125	6.3	788	7.017	1987	37.589
160	6.3	1008	8.981	2433	48.114

In Table 10 the power loss for each metre length of busbar at a current of 500 A is shown, calculated at the estimated working temperature (which is different for each size - see '2.0 Current-Carrying Capacity').

Table 10 – Resistance and Power Loss at 500 Amps

Width (mm)	Thickness (mm)	Area (mm ²)	Max Current (A)	Resistance at 20°C (μohm/m)	Resistance at working temperature (μohm/m)	Loss at 500 Amp (W/m)
25	6.3	158	530	109.460	138.100	34.53
31.5	6.3	198	639	86.873	104.647	26.16
40	6.3	252	776	68.412	79.637	19.91
50	6.3	315	932	54.730	62.164	15.54
63	6.3	397	1127	43.436	48.462	12.12
80	6.3	504	1390	34.206	37.889	9.47
100	6.3	630	1662	27.365	29.982	7.50
125	6.3	788	1987	21.892	23.635	5.91
160	6.3	1008	2433	17.103	18.465	4.62

This data is plotted in Figure 38.

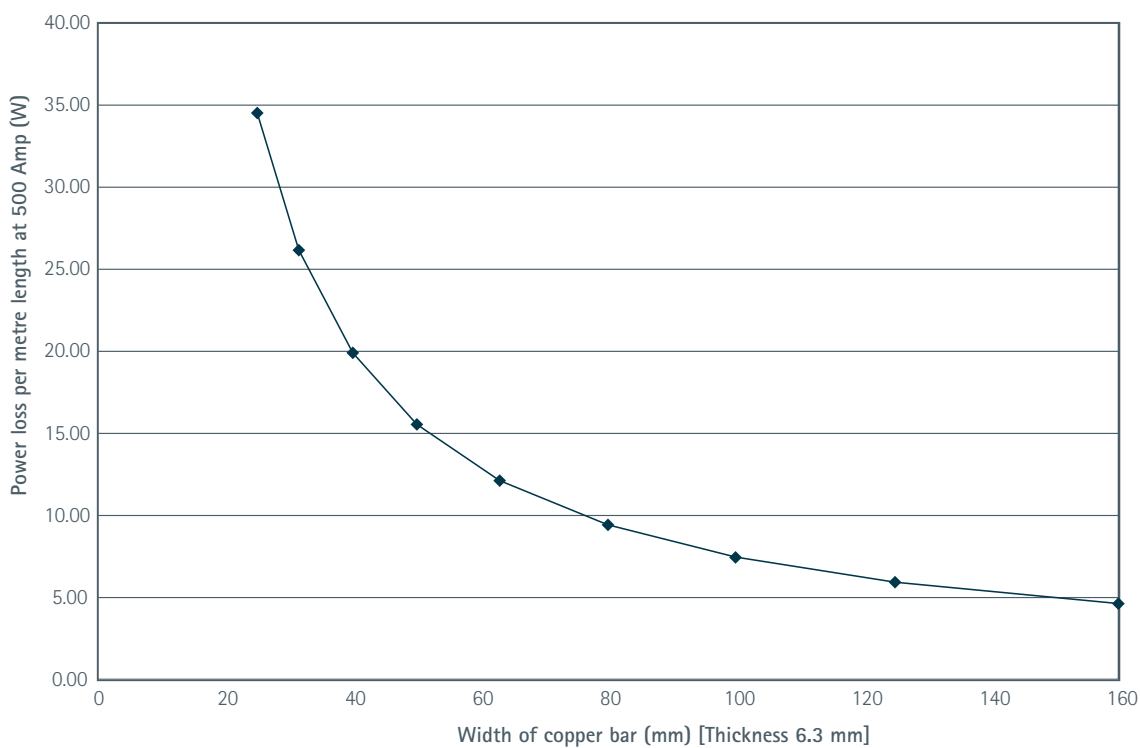


Figure 38 – Power loss versus width for 6.3 mm thick copper bars

The power loss needs to be expressed in terms of money by converting to energy loss (by multiplying by the operation time) and multiplying by the cost of energy. For the purposes of this exercise, the cost of energy is assumed to be 0.15 Euro per kWh. Table 11 and Figure 39 show the energy cost per metre for a range of operation times.

Table 11 – Energy Cost per Metre for Various Widths of Copper Bars at 500 A Load

Width (mm)	Cost of Energy (€ per metre)				
	2000 hrs	5000 hrs	10 000 hrs	20 000 hrs	50 000 hrs
25	10.36	25.89	51.79	103.58	258.94
31.5	7.85	19.62	39.24	78.49	196.21
40	5.97	14.93	29.86	59.73	149.32
50	4.66	11.66	23.31	46.62	116.56
63	3.63	9.09	18.17	36.35	90.87
80	2.84	7.10	14.21	28.42	71.04
100	2.25	5.62	11.24	22.49	56.22
125	1.77	4.43	8.86	17.73	44.32
160	1.38	3.46	6.92	13.85	34.62

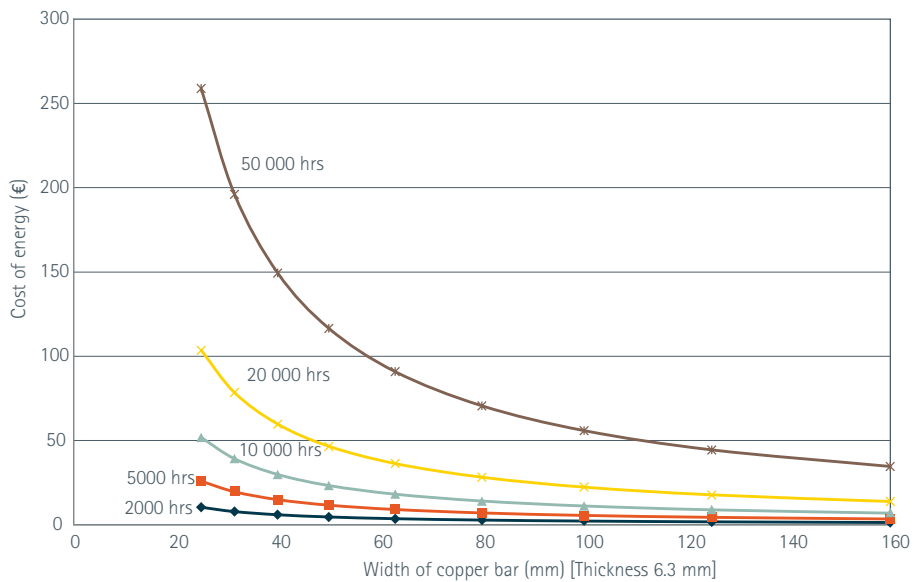


Figure 39 – Cost of energy loss per metre versus width for 6.3 mm thick copper bars for a range of operating times

By comparison with the material costs in Table 9 it is immediately apparent that, for any significant operational life, the cost of energy is by far the dominant element in the total cost of the system. Consider, for example, the 5000 hour operation case.

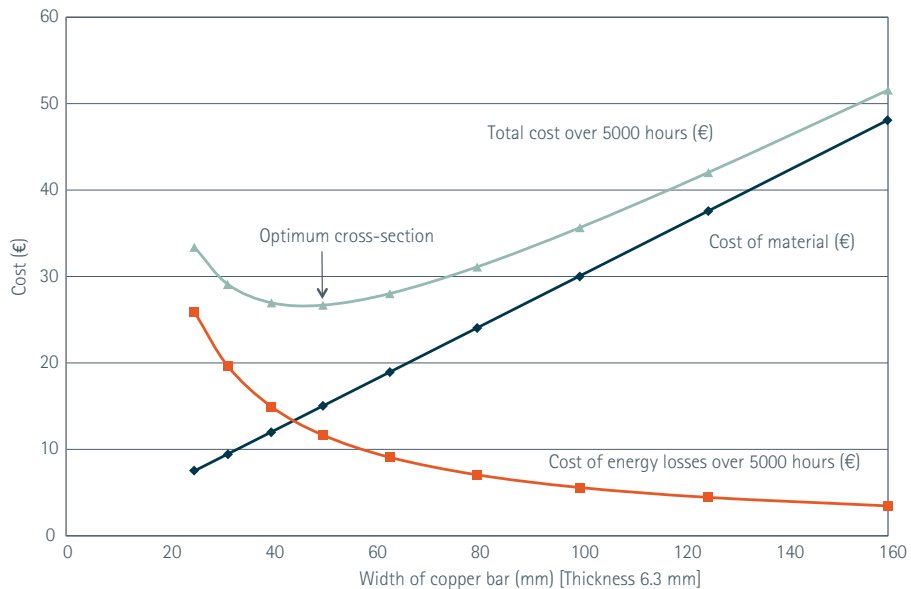


Figure 40 – Total cost per metre versus bar width for 5000 hours operation at 500 A load

Figure 40 shows the total cost, material cost (from Table 9) and energy cost (from Table 11) per metre of bar. As the width of the bar increases, the cost of material increases linearly, while the cost of energy decreases super inversely as the resistance and temperature decrease. The total cost curve shows a clear minimum where the total cost is optimised between investment cost (material) and operating costs (energy).

Because the cost of energy is proportional to operation time, the optimum bar width also increases with operation time, as shown in Figure 41, which plots the total cost per metre of bar for a range of operation times. As operation time increases, the optimum bar width increases.

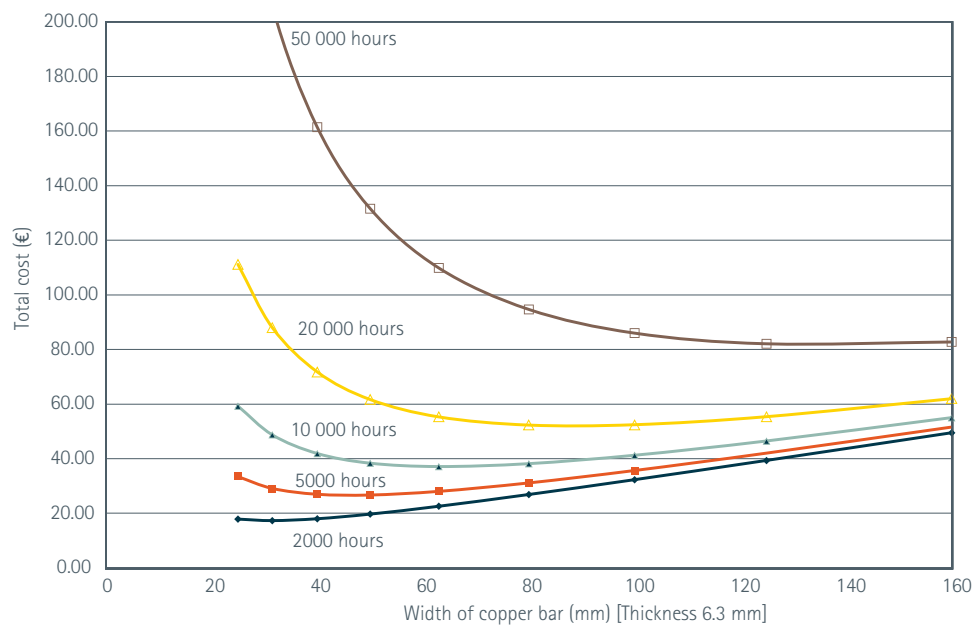


Figure 41 - Total cost per metre of bar versus bar width for a range of operating times

Figures 40 and 41 illustrate two important points:

At the minimum bar size – i.e. the size that would be selected by conventional methods – the cost of lifetime energy is many times the cost of the conductor; a factor of approximately 3.4 at 5000 hours. In fact, such a bar wastes its own cost in energy in less than 1500 operational hours, at the material and energy costs used in this example.

The minimum of the total cost curve is shallow, meaning that there is some latitude for judgement in the selection of the final size with a high degree of confidence in the outcome. For example, if the operational hours were not well known, but could be expected to be between 20 000 and 50 000 hours, a 100 mm bar could be confidently selected, being a little over optimum size for 20 000 hours and a little under optimum size for 50 000 hours.

Figure 42 is an alternative plot of the data in Figure 41 showing the optimum current density for a range of operating hours. As would be expected, the optimum current density reduces as operating hours increase.

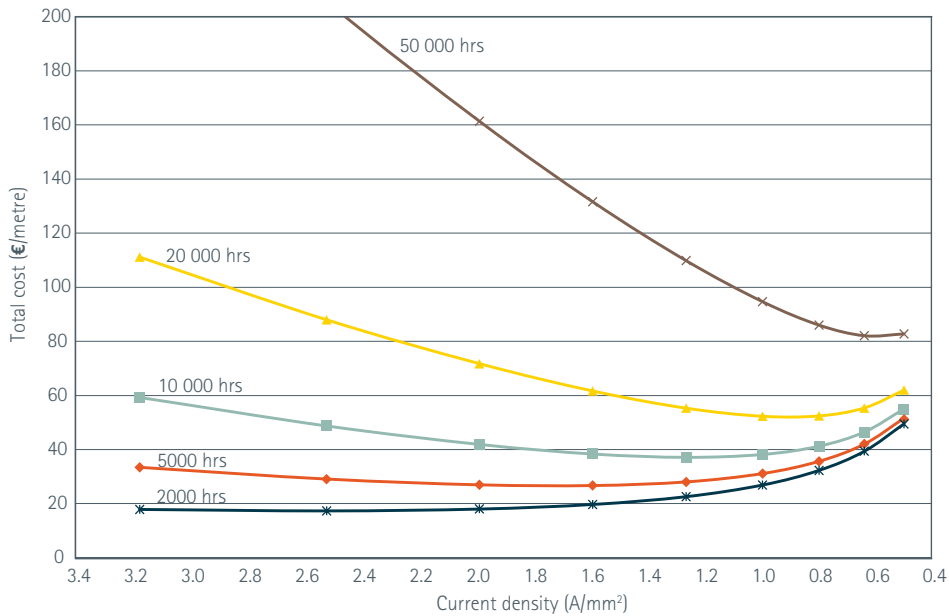


Figure 42 – Total cost per metre against current density for a range of operation times

Figure 43 shows the estimated working temperature plotted against bar width at 500 A load assuming an ambient of 35°C. As would be expected, lower current density results in reduced temperature rise, bringing the benefit of increased reliability due to reduced thermal stresses on joints and mountings, as well as optimised lifetime costs.

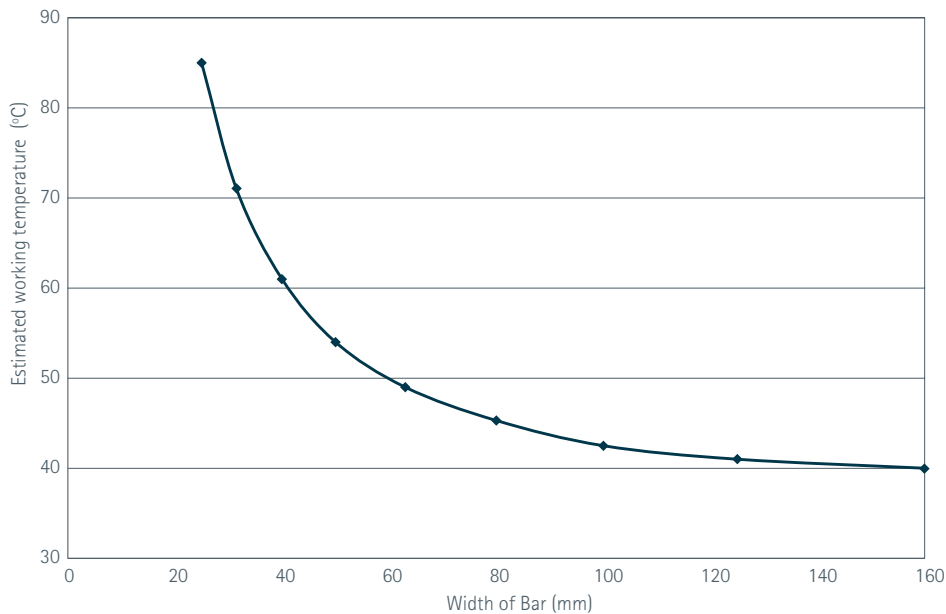


Figure 43 – Estimated working temperature versus width of bar (mm) for 500 A load

So far, this simple analysis has ignored the time value of money; to make the argument credible to financial managers, that must be corrected. In Table 12 the discount factors from Table 8, the material cost figures from Table 9 and the cost of energy loss figures from Table 11 are used to calculate the net present value – i.e. the discounted cost – of operating each metre of bar for 5 years at 2000 hours load per year. The assumed discount rate is 5% but for the sake of clarity, no account is taken of inflation or load growth.

In this case, because the energy is paid for throughout the operating time, no discount is applied to Year 0. Local accounting practice may require discounting to be applied to Year 0 in some cases.

Table 12 – Present Value (€) per Metre of Bar

Discount Factor			Cost of Energy (2000 hours per year)					Total	Total
			Year 0	Year 1	Year 2	Year 3	Year 4		
Bar Width (mm)	Power Loss per Metre (watt)	Cost of Bar (euro)	1	0.952	0.907	0.864	0.823		
25	34.53	7.518	10.36	9.8627	9.3965	8.9510	8.5263	47.10	54.61
31.5	26.16	9.472	7.85	7.4732	7.1200	6.7824	6.4606	35.69	45.16
40	19.91	12.029	5.97	5.6834	5.4148	5.1581	4.9133	27.14	39.17
50	15.54	15.036	4.66	4.4363	4.2266	4.0262	3.8352	21.18	36.22
63	12.12	18.945	3.63	3.4558	3.2924	3.1363	2.9875	16.50	35.45
80	9.41	24.057	2.82	2.6846	2.5577	2.4365	2.3209	12.82	36.88
100	7.45	30.071	2.24	2.1325	2.0317	1.9354	1.8435	10.18	40.25
125	5.93	37.589	1.78	1.6946	1.6145	1.5379	1.4649	8.09	45.68
160	4.62	48.114	1.38	1.3138	1.2517	1.1923	1.1357	6.27	54.39

Figure 44 shows the comparison between the discounted and non-discounted cost, this time for a 10 year life.

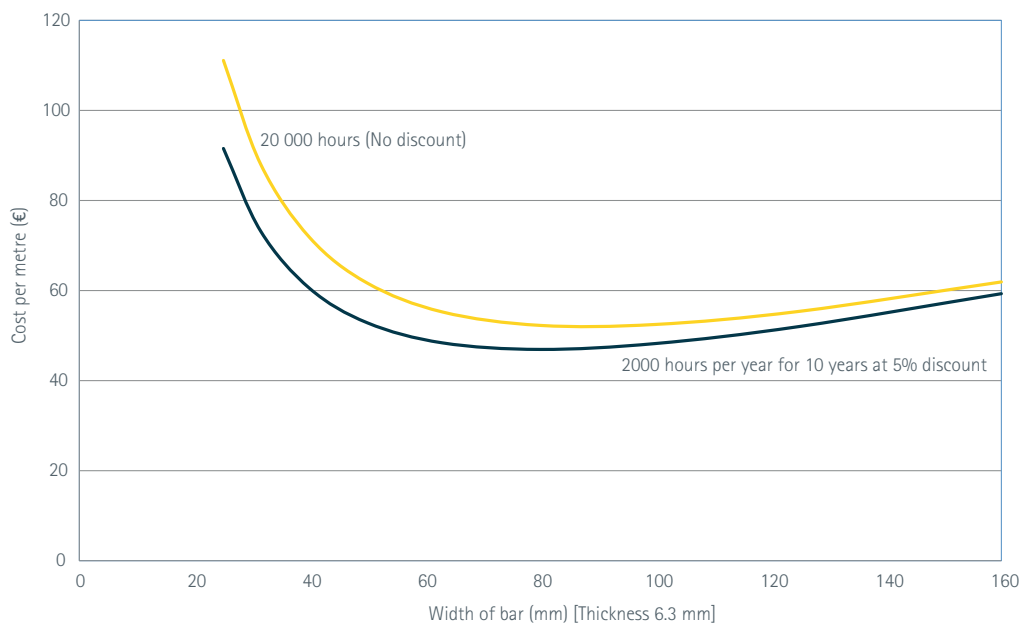


Figure 44 – Cost per metre (€) against bar width for a) 20 000 hours operation without discount and b) 2000 hours per year for 10 years at 5% discount

The effect of discounting is, of course, to progressively reduce the value of the later years and therefore the total cost. But, as Figure 44 clearly shows, it also shifts the minimum cost bar width towards a lower value. This is an obvious conclusion if discounting is viewed as reducing the operating time in later years instead of the cost of each operating hour in later years.

A warning is appropriate at this point; using exaggerated discount rates will reduce the viability of any investment in the same way as imposing too-short a payback period would, so it is important that discount rates are chosen with care and without prejudice.

3.2.4 End of Life Costs

At the end of life the installation must be removed and the materials recycled. In electrical systems the copper conductor has significant value, making recovery worthwhile; however, it is so far into the future, it is often assumed that the discounted value will be low. However, commodity prices are very volatile with an underlying upward trend so, if material price inflation is included in the calculation, the NPV of the residual material may be significant.

An additional problem is that the task of removing the installation is usually carried out by a third party under contract, so the operator sees a contract cost, while the third party receives the revenue from recycled materials.

3.3 Conclusion

Life cycle costing provides a more realistic view of the cost of a project and is particularly useful in comparing two or more design options. The curve of LCC versus conductor size is quite flat near the minimum; selecting the largest conductor size in range provides both a short term optimum and reduced exposure to future energy price increases.