The Problem with "Payback"

(originally presented at the 1997 IPENZ Annual Conference, Wellington)

Rob Bishop
Technical Director
Energy Solutions Ltd.
P.O. Box 12-558, Wellington

Introduction

There are many different financial indicators that can be used to make investment decisions. However, “Simple Payback" is typically the only one used for energy efficiency investments. This oversimplified value is rarely used in other economic analysis and tends to give misleading results.

The following example shows how the main financial indicators can be used to analyse the same problem, of how much ceiling insulation is cost effective and how the other indicators compare to "Simple Payback" analysis.

This example shows the following:

• Life-cycle costing, net present value, benefit-to-cost ratios, internal rate of return, and cost-of-saved-energy calculations all give the same results, if the same inputs (costs, investment lifetimes, discount rates) are used. For this example, they show the optimal insulation thickness to be about 250 mm.

• Simple payback, although very simple to use, is not the best indicator for financial calculations. It does not account for the time value of money, and can lead to under-investment in efficiency, and again much lower financial returns. A "two-year marginal payback" criterion will result in only 100 mm insulation thickness.

• The optimal insulation thickness is the point where the overall (net) savings are the greatest. This is where the marginal costs equal the marginal benefits. Analysing marginal costs and returns are the most appropriate method of optimising financial decisions, especially for energy efficiency investments. Comparing on the margin will allow the greatest net savings.

• If average costing is used, there may be over-investment in efficiency, and overall (net) returns may be much lower than otherwise. A “ two-year average payback" will be achieved at 600 mm of insulation.

• "Averaged simple payback" allows the problems with both averaging and “payback” to roughly cancel each other out. This is a very crude, sloppy method for determining investment. However, it is the measure that is almost always used.

The measure of "simple payback" is commonly the only indicator used for energy efficiency investment decision-making. However, this oversimplified value is rarely used in other economic analysis, and tends to confuse energy saving investments.

The following example shows six different ways of looking at the problem of how much ceiling insulation is cost effective. The analysis uses basic heat transfer equations, and the assumptions (listed at the end of the paper) arc considered reasonable for most of New Zealand in 2003.

Cost of Heat Loss Energy

The annual cost of heat loss can be calculated through a square metre of insulated ceiling, as a function of the insulation's thickness as shown in Figure 1. As can be seen, this is a classical "diminishing returns" graph, with heat losses falling much more steeply for the first increments of insulation (at the left end of the graph) than for later ones (near the right end).

The cost of heat loss starts at about $12/m^2, drops rapidly to about $2/m^2, then continues decreasing indefinitely, as more and more insulation is added.

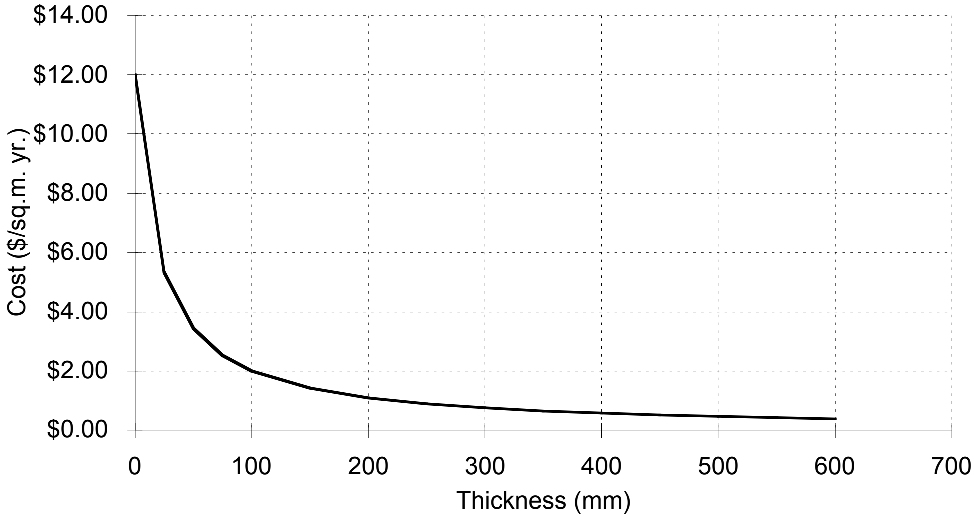

Figure 1 – Cost of heat flowing through a square metre of ceiling

Cost of Insulation

Insulation costs depend on materials and labour. Generally, in a ceiling, doubling the thickness of insulation also doubles both material and labour costs, so insulation costs can be considered to increase linearly with insulation thickness. (Actually, there would also be some fixed cost attached, for estimating the work required, driving to the job site, setting up, invoicing the customer, etc.)

The solid line in Figure 2 shows the total capital cost of the insulation, in dollars per square metre, as a function of the insulation's thickness, and the dashed line shows the annual cost, assuming the insulation is to be paid for on the house's mortgage.

The ability to finance the cost of the insulation over time on a mortgage is what makes thicker insulation cost-effective.

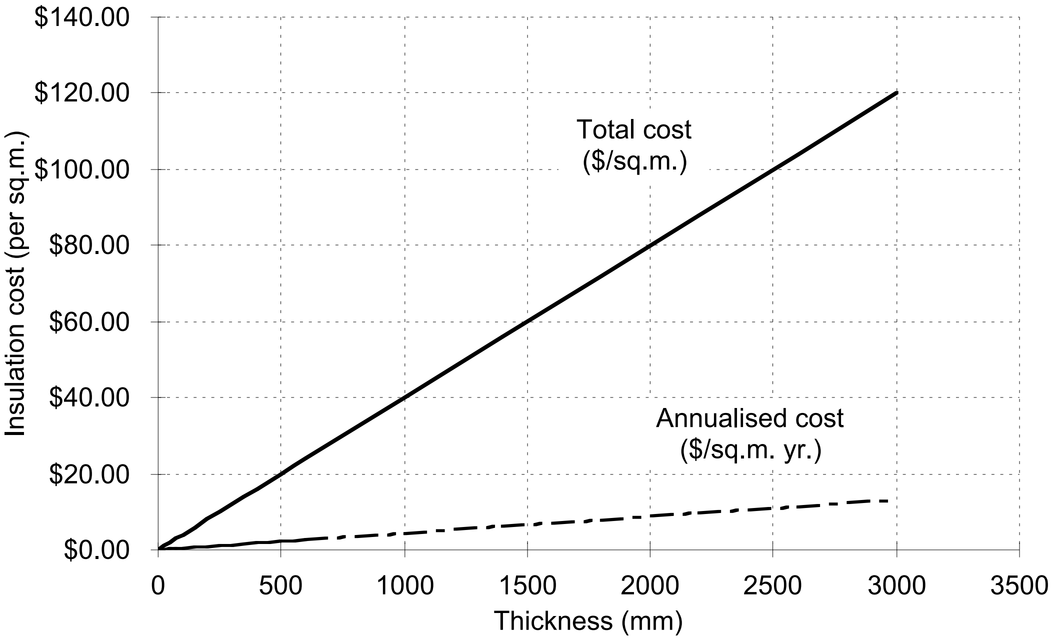

Figure 2 – Cost of insulation to reduce heat losses

Energy Savings (another way of looking at energy costs)

Figure 3 is basically, Figure 1 upside down. Instead of showing the costs of the heat loss at each insulation thickness, it shows the savings, compared to no insulation, as a function of insulation level. Again, this shows the same diminishing returns effect.

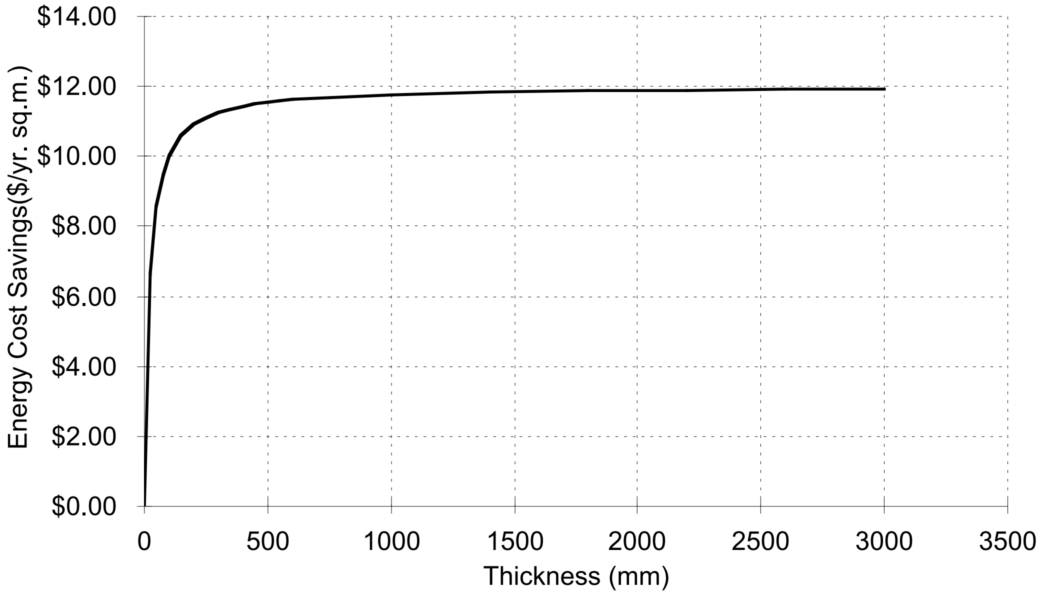

Figure 3 – Savings from adding insulation

Energy Savings Compared to Insulation Costs

Figure 4 is similar to Figure 3, except that the annual costs are also plotted on the same axes. The thickness where the total cost equals the total benefit is shown to be at about three metres of insulation. This measure could be used (abused?) to show that this is the cost-effective level of insulation, but this hardly seems practical.

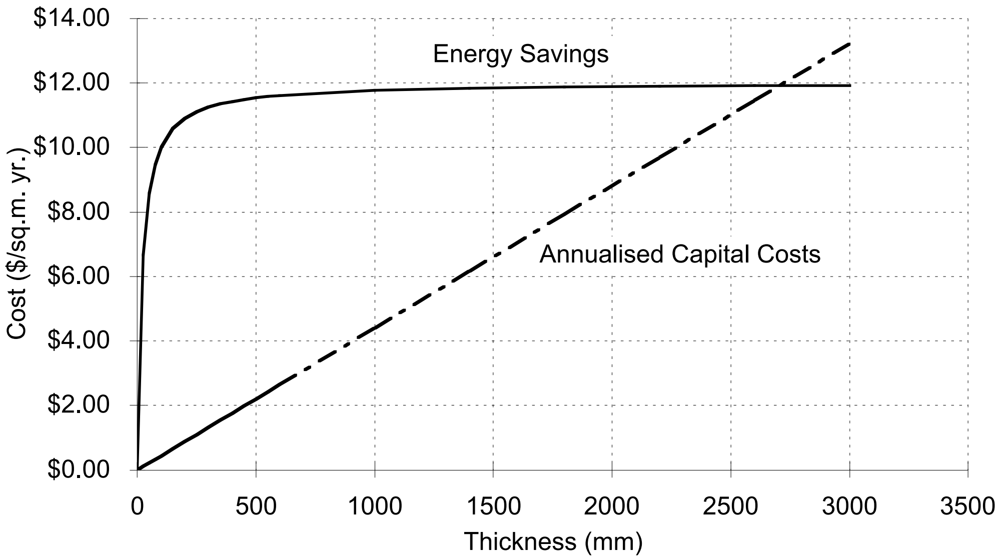

Figure 4 – Savings plotted on the same scale as costs

Averaged Simple Payback

Because insulation costs are taken to rise linearly with thickness, we can directly plot the energy savings from the insulation as a function of the capital (not annual) cost of insulation, instead of plotting as a function of thickness. (For measures where the price does not rise linearly with thickness, this can still be done, but the shape of the savings curve is not as smooth.)

Figure 5 shows the savings plotted against the capital cost. We'll call this the "savings curve". There are also lines of "Simple Payback" plotted on this figure. These start at zero savings, where there is no insulation, and show the savings required for each level of cost to yield a given "Simple Payback". For example, along the "1 yr SPB" line a $10 cost shows a $10/yr saving, along the "2 yr SPB" line a $20 cost shows a $10/yr saving, etc.

As can be seen, the savings curve crosses the "1 yr SPB" line at a cost of about $11/sq. m., crosses the "2 yr SPB" line at a cost of about $23/sq. m., and the "4 yr SPB" line at a cost of about $47/sq. m. Note that the energy savings are not significantly different at any of these insulation thicknesses.

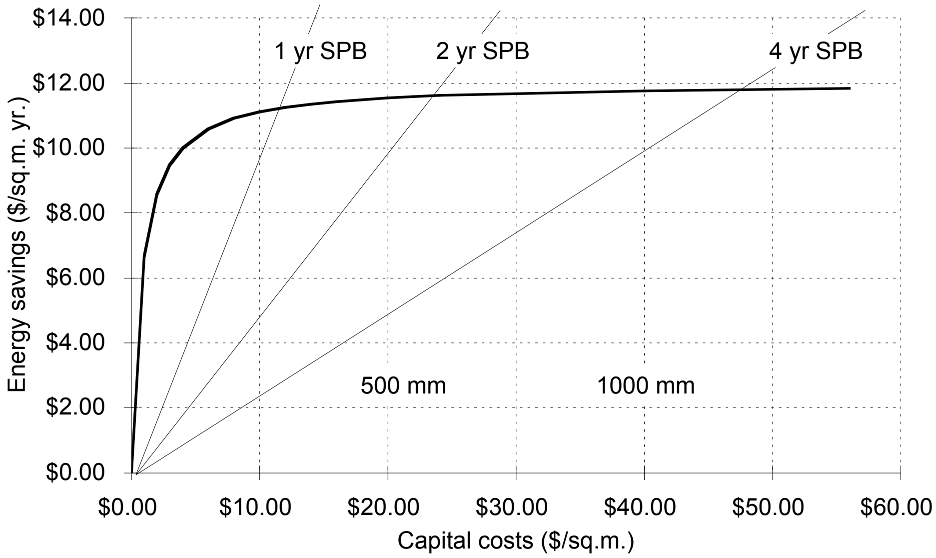

Figure 5 – Savings plotted versus costs, to show paybacks

The "Simple Paybacks" on Figure 5 are the averaged paybacks. They show that an averaged two-year simple payback can be obtained at about 600 mm insulation thickness, and a four-year payback at about 1200 mm. Likewise, Figure 4 shows that about 3 metres of insulation would repay its costs over the term of the mortgage.

However, averaged paybacks are not the most appropriate financial indicator for optimisation. It is more important to know how much each increment of insulation saves. If the relative savings are so small, why raise the insulation thickness from 300 mm to 600 mm?

Marginal Simple Payback

Marginal simple payback can be shown by calculating the marginal savings for each (50 mm) increment of insulation, and dividing by the marginal cost of that increment. This is shown in Figure 6, which is a variation of Figure 5. In addition to the lines of average payback, Figure 6 also shows a line of "two-year marginal payback" which is parallel to the two-year average payback line, and tangent to the curve of savings.

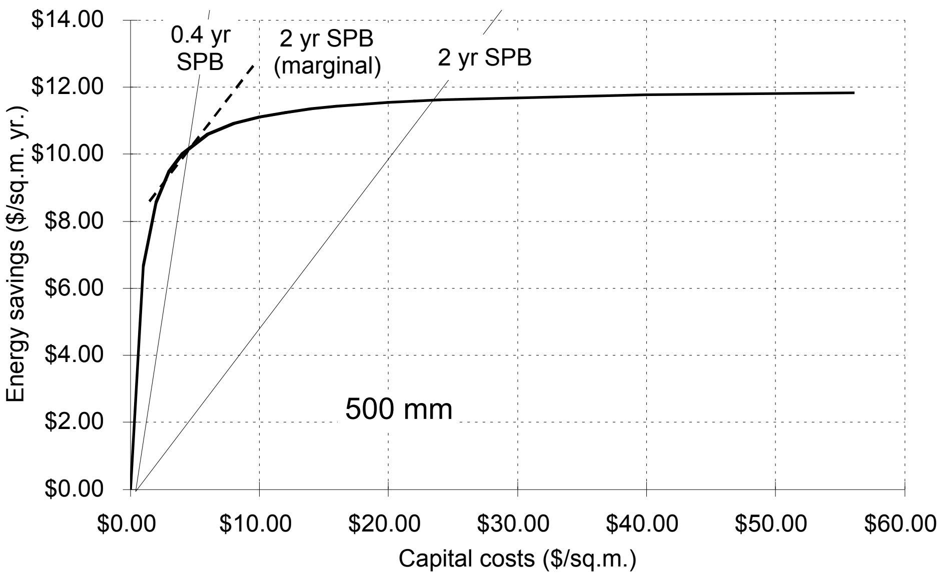

Figure 6 – Savings plotted versus costs, again, to show “marginal” payback

Figure 6 shows that the last increment of insulation that can justify a two-year simple payback itself is that from 75 mm to 100 mm. In this case, the average payback for the whole amount of insulation is about 0.4 years.

This illustrates the difference between averaged and marginal returns, when the simplistic "Simple Payback" indicator is used. The same effect occurs between marginal and averaged returns with any other financial indicator, as will be shown.

Figure 7 shows the averaged and marginal "Simple Paybacks" as a function of insulation thickness for this example. The solid line is the Marginal Simple Payback (abbreviated SPB) and the dashed line is the Averaged Simple Payback.

As can be seen, the marginal simple payback line reaches 2 years for 100 mm insulation thickness, while the average line reaches there only after 600 mm thickness. This corresponds to the results shown in Figures 5 and 6.

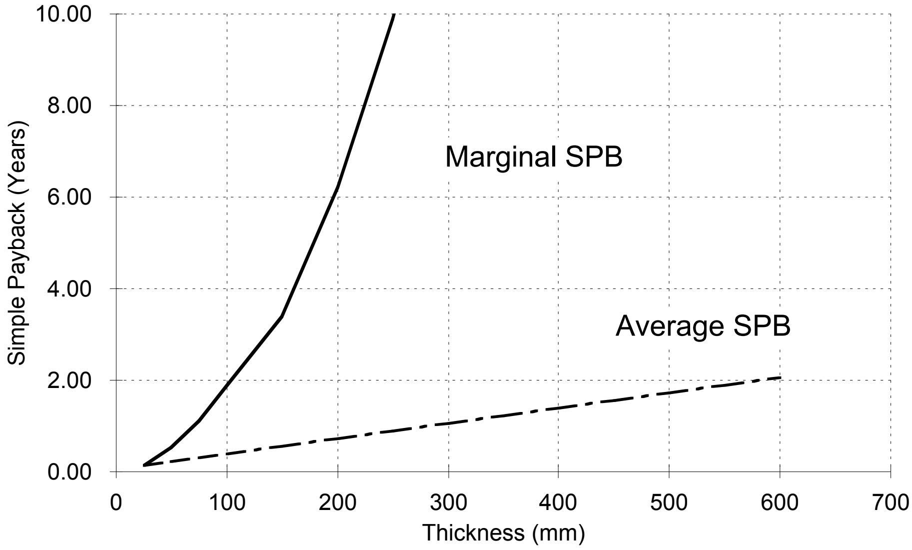

Figure 7 – Simple paybacks plotted as a function of insulation thickness

Thus, if a customer requested "insulation up to a two-year payback" either a 100 mm or 600 mm thickness would be justifiable, though at a 500% capital cost difference.

Benefit-to-Cost Ratio

Now, we move away from simple paybacks to a more sophisticated (but still simple-to-use) indicator, called the benefit-to-cost ratio (BCR). This is the ratio of benefits (annual energy savings) to costs (annualised capital costs). Generally a BCR greater than one indicates a beneficial investment, though often projects are ranked in terms of BCR.

Figure 8 shows the energy savings (benefits) and annualised capital costs (costs) of the insulation, in a repeat of Figure 4.

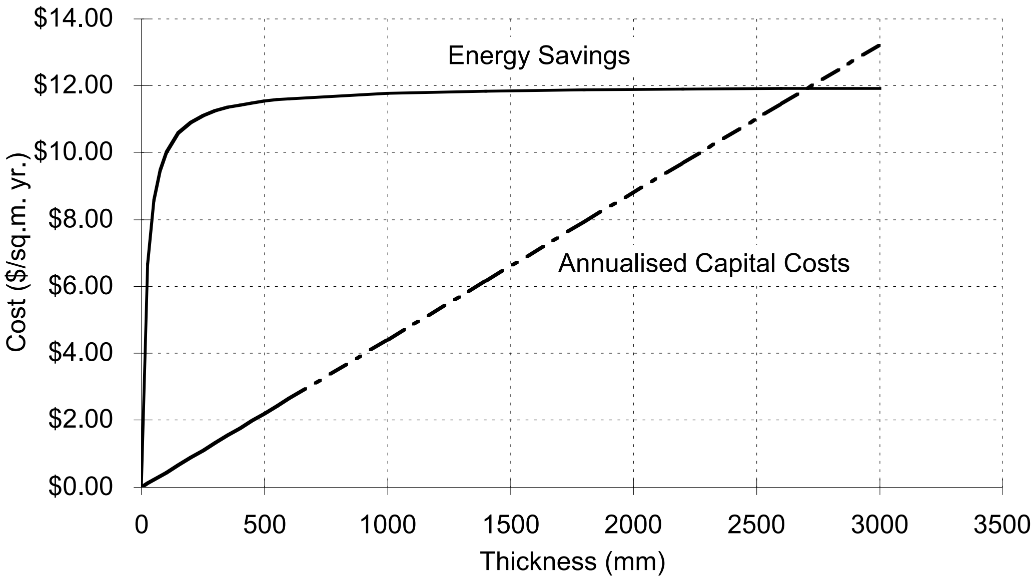

Figure 8 – Total costs and savings (benefits) from insulation

When we divide the benefits by the costs, from Figure 8, above, we get the averaged Benefit-to-Cost Ratio, as shown in Figure 9. Interestingly, this ratio does not drop below one until about three metres insulation thickness, at which point the total annual costs for the insulation exceed the total annual savings.

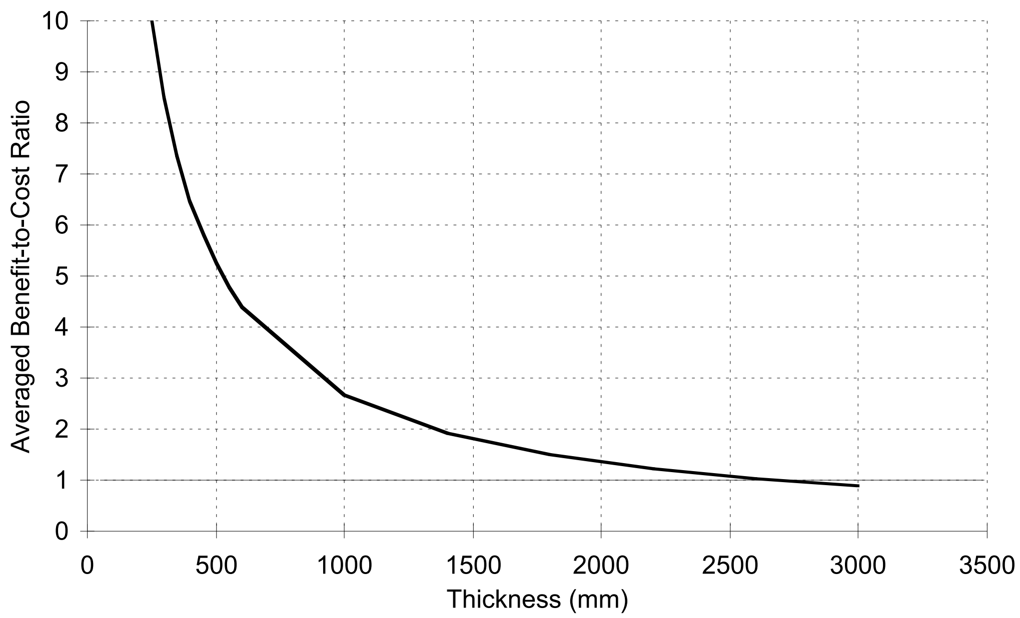

Figure 9 – Averaged Benefit-to-Cost ratio

However, we are probably more interested in when the net benefits are maximised. For this, we need to calculate the marginal Benefit-to-Cost Ratio.

We can calculate the increase in the savings for each increment of insulation in Figure 8 above, and the increase in costs for the same increment. These are plotted in Figure 11 as the marginal annual benefits of each millimetre increment of insulation thickness, shown as the declining solid line, and the marginal annual cost of each millimetre increment, shown as the (horizontal – indicating constant marginal cost) dashed line.

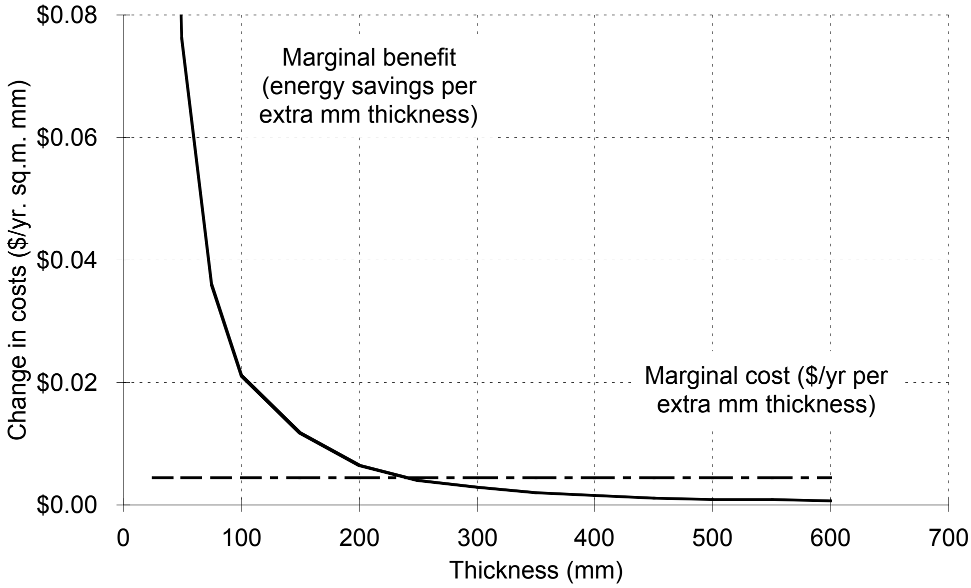

Figure 10 – Marginal costs and benefits of each incremental thickness of insulation

As can be seen, the marginal benefits decline below the marginal costs at about 250 mm insulation thickness. This is the same information as on the previous figures, but presented slightly differently. The marginal benefit (energy savings) is greater than the marginal cost for all thicknesses up to 250 mm. Thus the most cost-effective insulation level is 250 mm.

When we divide the marginal costs by the marginal benefits, we get the benefit-to-cost ratio, as shown in Figure 11. The solid grey line shows the target benefit-to-cost ratio of 1.0. When the insulation thickness is increased beyond 250 mm, the solid line drops below this target line, the benefit-cost ratio drops below one, and the investment will cost more than it saves. This is considered "uneconomic".

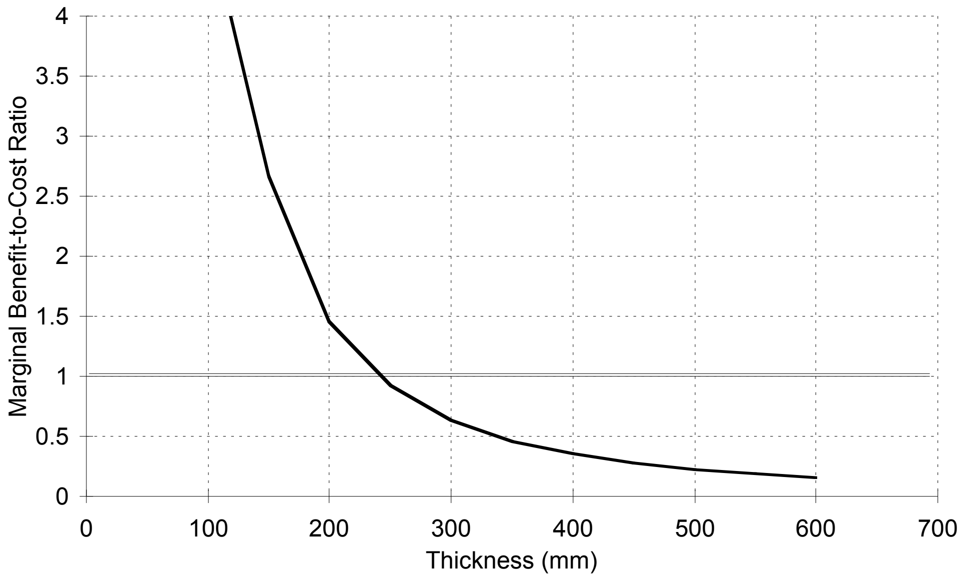

Figure 11 - Marginal Benefit-to-Cost ratio

Life Cycle Costs

Another important financial indicator is Life Cycle Costing (sometimes abbreviated LCC). This calculates the total cost of energy and insulation, and seeks the minimum cost point. This is shown in Figure 12, where the energy cost data from Figure 1 is shown as the short-dashed line, the annualised insulation cost data from Figure 2 is shown as the short-long dashed line, and the sum of these two is shown as the solid line.

As can be seen, the minimum total (Life Cycle) cost occurs again at about 250 mm insulation thickness. As insulation thickness is increased from zero, the total costs drop sharply, then flattens out and reaches a minimum cost at slightly over 200 mm thickness. As insulation is increased further, the total costs climb slowly, as the marginal insulation costs now exceed the marginal energy savings. If the graph was extended far enough, the total cost would rise to equal that at zero insulation thickness ($12/sq.m.yr) at about 3 metres insulation thickness.

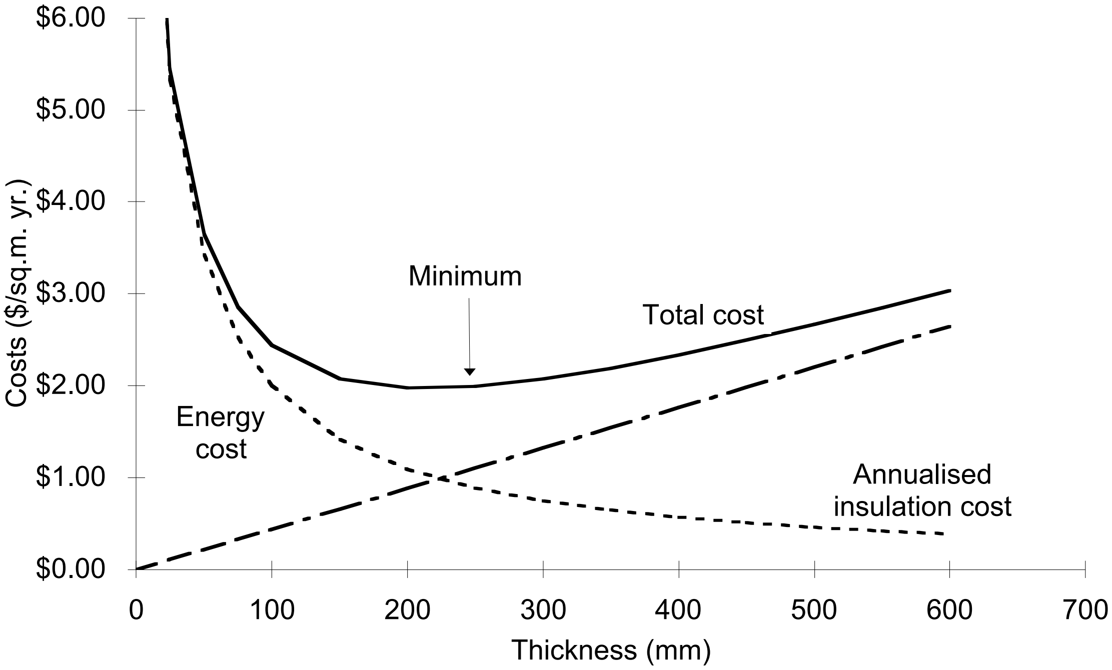

Figure 12 – Life cycle costs

An advantage of the LCC presentation is that it lends itself directly to variations of parameters. For example, Figure 13 shows the effect of doubling energy prices compared to today's (due to supply uncertainties, environmental externalities, carbon taxes, etc.). As can be seen, with a higher energy price, the lowest total cost point shifts toward higher insulation levels.

This same type of presentation could also be used to show the effects of different discount (interest) rates, loan terms, insulation costs, climate conditions, etc.

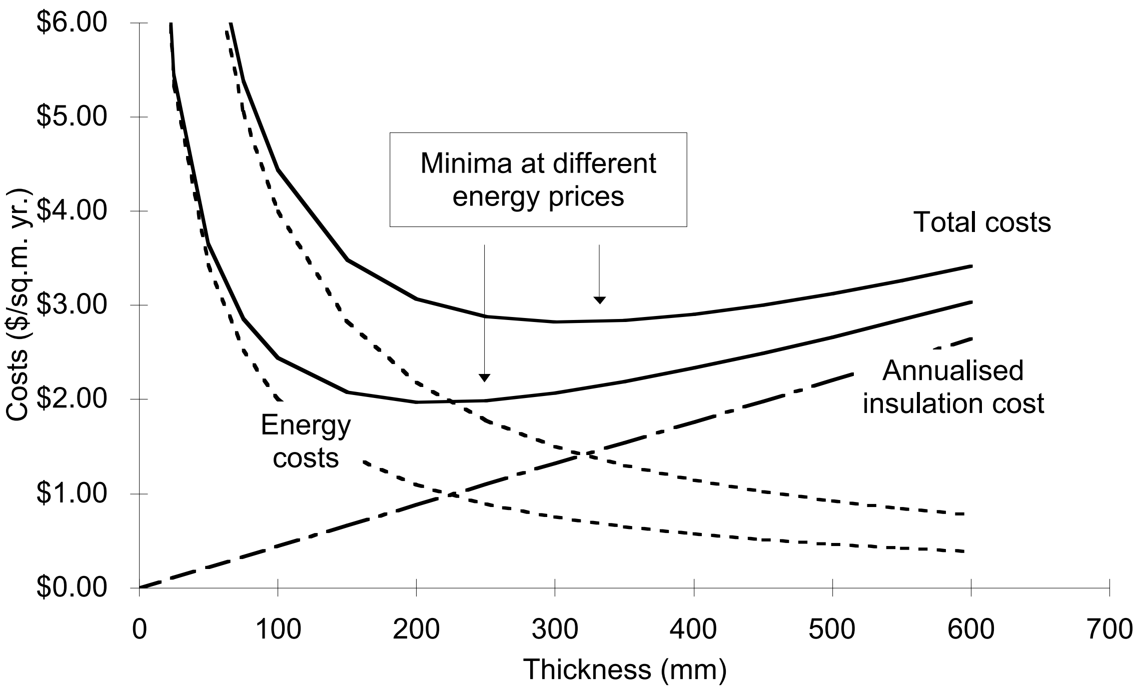

Figure 13 – Life cycle costs at different energy prices

Net Present Value

Another method of analysing this problem is with "Net Present Value". This is very similar to Life-Cycle Cost, except that the total net savings are counted, looking for the maximum, instead of the total costs, looking for the minimum.

Figure 14 shows the Net Present Value (NPV) when the total insulation costs (from Figure 2) are subtracted from the present value of the energy savings (multiplied by UPW from Figure 3). Again, the greatest NPV occurs at about 250 mm insulation thickness showing this is the optimum thickness.

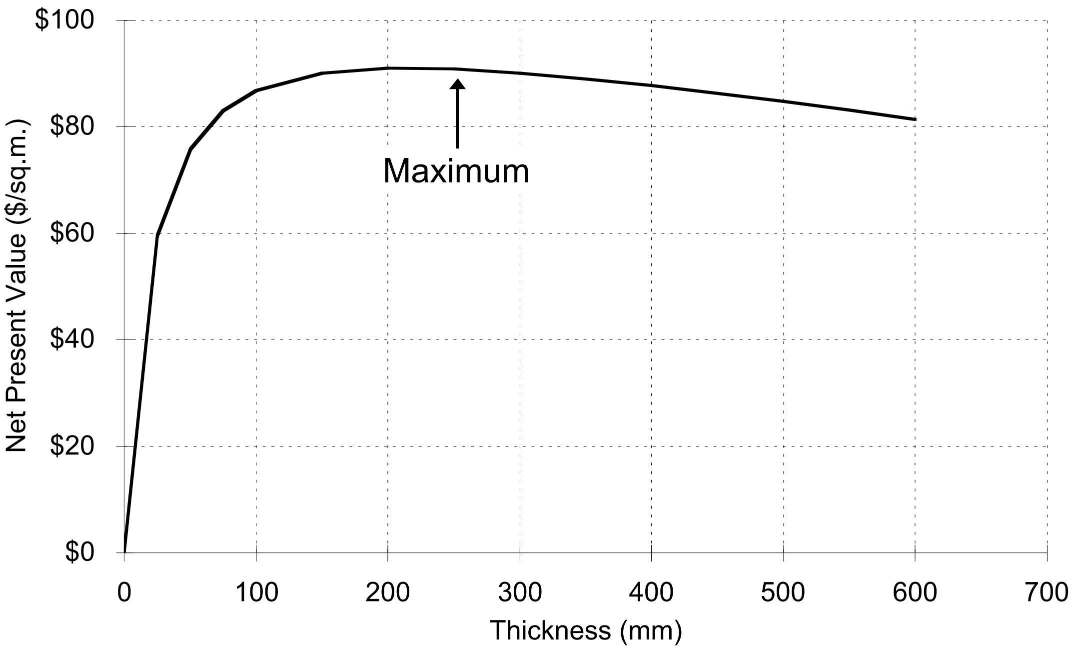

Figure 14 – Net Present Value as a function of insulation thickness

Internal Rate of Return

Many organisations base their financial decisions on an indicator known as "Internal Rate of Return". This is the discount rate at which the net present value becomes zero. In effect, this is what constant rate of return a competing investment would need to give to yield the same cash flow as the investment in question (here, insulation).

Figure 15 shows the marginal internal rate of return (IRR) for each increment of insulation thickness. As can be seen, just above 200 mm the marginal IRR drops below 10%, which is the discount (mortgage) rate that the insulation is assumed to be financed at. Above 300 mm thickness, the IRR drops to near zero. This shows that using the IRR criterion, the optimum thickness is just over 200 mm.

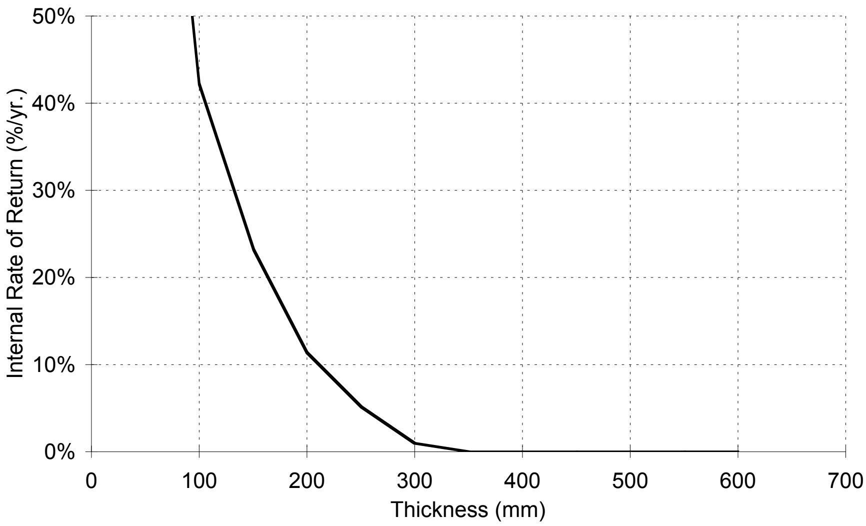

Figure 15 – Marginal Internal Rate of Return

Again, an averaged IRR can be calculated, by comparing the whole amount of insulation compared to none at all (instead of comparing the effect of each increment, to get the marginal IRR). The averaged IRR is shown in Figure 16.

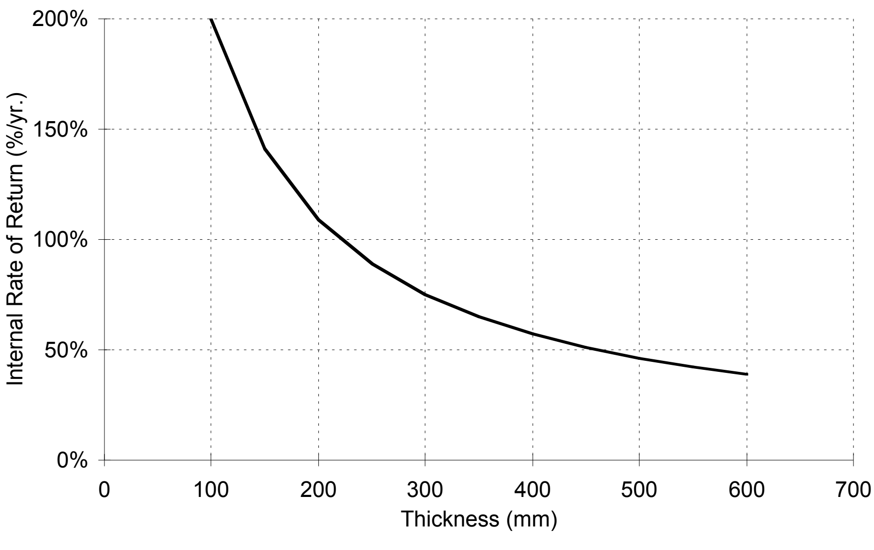

Figure 16 – Averaged Internal Rate of Return

As can be seen, the averaged IRR stays quiet high for all thicknesses on this graph.

Cost of Saved Energy

Finally, the Cost of Saved Energy (CSE) can be calculated, as the equivalent cost that energy would have to be purchased for to make the investment just economic (the formula for calculating this is shown in the Appendix). This is shown in Figure 17, below, on both an average and marginal basis. As can be seen, at about 250 mm insulation thickness, the equivalent marginal Cost of Saved Energy is 10¢/kWh, the same as our assumed energy purchase price. At this point, the last increment of insulation saves energy for a lower cost than it can be purchased, so this is the optimal thickness.

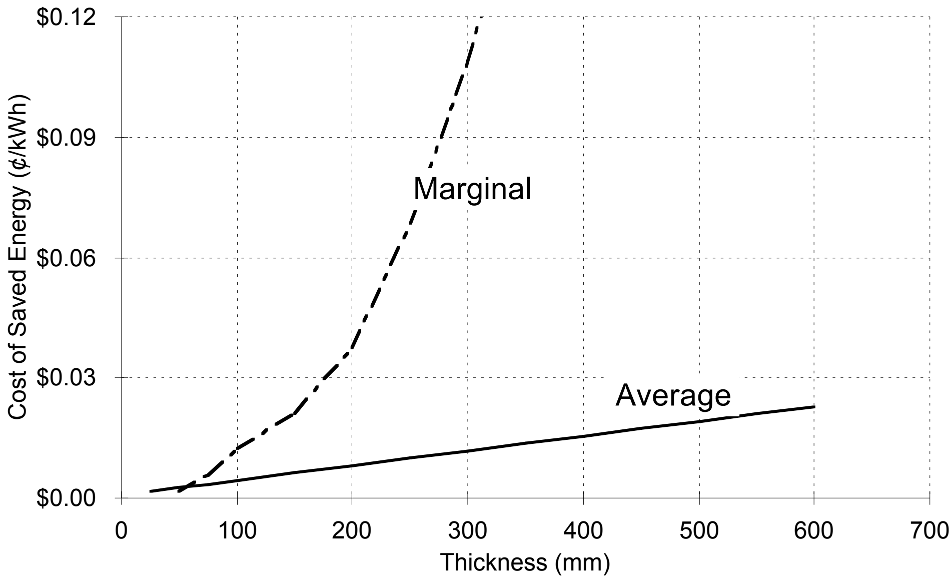

Figure 17 – Cost of Saved Energy

Summary

As shown above, all the normal financial indicators (LCC, NPV, BCR, IRR, CSE) indicate that about 250 mm of insulation is the optimal thickness, based on the stated assumptions. This is the level where the Life Cycle Costs are lowest, the Net Present Value the highest, the Marginal Benefit-to-Cost ratio equals one, the Marginal Internal Rate of Return equals 10%, and the Marginal Cost of Saved Energy equals 10¢/kWh.

If the "Simple Payback" criteria were used, and a marginal two-year simple payback were chosen as the financial indicator, then about 100 mm of insulation would have been indicated as most cost-effective. This would have led to about 60% higher energy use, a 10% lower Net Present Value, and 10% higher Life Cycle Costs, than the optimal level from the other indicators.

If the averaged "Simple Payback" were used, about 600 mm of insulation would have been used, which would have led to about 60% higher Life Cycle Costs or 20% lower Net Present Value.

If the averaged values of the other indicators were used, the cost-effective insulation thickness would have been indicated to be about 3000 mm, which would have led to 500% higher Life Cycle Costs, and zero Net Present Value.

In conclusion, although "Simple Payback" is an easy-to-use financial indicator for ranking investment returns independently of their value over time, if it is used for decision-making about the level of investment (especially in energy efficiency) it will give misleading results.

If very conservative investment decisions are desired, then a correspondingly high discount rate (40%+/year) should be used explicitly, rather than mistakenly using "Simple Payback" on which to base investment decisions.

Appendix – Formulae

Annual heat loss (kWh/m^2 yr) = number of °C-days/yr x 24 hours/day ÷ R-value (m^2 C°/W)

Simple payback (yrs) = Capital cost ($ or $/sq.m.) ÷ Annual energy savings ($/yr or $/sq.m. yr.)

Benefit : Cost Ratio = Annual energy savings ($/yr) ÷ Annualised [insulation] cost ($/yr)

Annual costs (of capital investment) = Capital cost ($ or $/sq.m.) x UCR (%/yr)
Where UCR = "Uniform Capital Recovery" factor = (i x ((1+i)^N))/(((1+i)^N)-1)
i = discount rate or interest rate, in %/yr
N = number of years of analysis

Life Cycle Cost = Annual energy cost ($/yr) + Annual [insulation] cost ($/yr)

Net Present Value = Total discounted energy savings ($) – Capital Cost ($)

Total discounted [energy] savings = Annual energy savings ($/yr) x UPW (yr)
Where UPW = "Uniform Present Worth" factor = (((1+i)^N)-1)/(i x (1+i)^N)

Internal Rate of Return = discount rate, adjusted such that Net Present Value = 0

Cost of Saved Energy ($/kWh) = Capital Cost ($) x i /(Annual savings (kWh/yr) x (1-((1+i)^-N)))

Appendix – Assumptions

The assumptions in this analysis are:

• the ceiling is above a heated house, exposed 2000 ºC-days/year. This corresponds to a house heated to 20ºC during the day and 16ºC at night, in a climate like Wellington's. There is no difference in the temperature the house is heated to as the insulation level changes. (Consider the house to be centrally heated with a timer thermostat.)

• the house is heated with electric resistance heat. The unit price of electric energy is 10¢/kWh. This cost is assumed to be constant, in real terms, over the period of the analysis. No credit is taken for reduced heating system size.

• the insulation is loosefill, with an insulation value (R-value) of R-2 per 100 mm thickness. No joist effects are counted. The insulation has an installed cost of $2.00/$m^2$ per 100 mm thickness (long-term settled thickness). (This corresponds to macerated paper, or loosefill cellulose.) The uninsulated ceiling has an R-value of 0.4 (m^2 C°/W).

• the insulation's cost is financed as attached to a house mortgage, of 20 years, at a 10%/year fixed rate with 20 equal repayments. This means that each annual payment will be 11.02% of the total cost.

• There are no taxation benefits considered (although the energy savings are tax free).