STUDY REPORT

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Life Cycle Costs of Selected Claddings for Non-Residential Buildings

I. C. Page

The work reported here was funded by the Building Research Levy

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Preface

This is the second of a series of reports prepared during research into life cycle costs of building materials and systems. The earlier report, reference (1) was on claddings in dwellings.

Acknowledgments

This work was funded by the Building Research Levy.

Note

This report is intended to assist designers by giving them a better understanding of the economic implications of choice of cladding materials. It focuses on selected materials commonly used in low-rise commercial, industrial and institutional buildings. Usually the cost of a building material is only one of the factors in the material selection process. This report describes a formal system for combining costs with other less tangible factors in the decision-making process.

LIFE CYCLE COSTS OF SELECTED CLADDINGS FOR NON-RESIDENDIAL BUILDINGS

BRANZ Study Report SR 97 **I. C. Page**

REFERENCE

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ABSTRACT

Life cycle cost analysis is a technique which allows for consistent comparisons of net costs of buildings and components throughout their lives. It enables valid comparisons to be made between materials with different initial and on-going costs, and with different life spans.

This report examines the life cycle costs of the most common roof and wall cladding materials (and their support structures), used in low-rise commercial and industrial buildings. The support structure costs are included since different claddings have different spanning capacities. Various maintenance options and environmental conditions are also described and analysed for each system.

Often the choice of material is based on other considerations than cost alone, and the report describes a method for combining quantitative data (such as costs) with intangible factors (such as aesthetics) in the material selection process. This is a method where materials are ranked for various attributes such as cost, appearance, impact resistance, etc. Each attribute is then given a weighting to arrive at a combined ranking which reveals the preferred material.

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1. SUMMARY

The main purpose of this report is to set out the life cycle costs of selected cladding systems commonly used in low-rise non-residential buildings. Secondary issues covered include a technique for the combination of intangibles (such as aesthetics) with costs in the material selection process, and the potential effect of a carbon tax on life cycle costs.

The materials considered in this report are:

- sheet steel, pre-coated and zinc/ aluminium coated steel only
- aluminium sheet
- fibre-cement sheet
- plywood sheet
- concrete tilt slab
- concrete masonry block.

Though this is a restricted list, it covers about 85% of wall cladding areas, and over 90% of roof cladding areas on new non-residential buildings, and additions to these buildings. This is for the year ending December 2001, based on the BRANZ buildings material survey. In some years these percentages are 5% to 10% lower, depending on the amount of large commercial projects undertaken, as these tend to use proprietary panel products. However, the focus of this report is low-rise buildings, which overwhelmingly use the materials listed above.

The main results of the report are:

- Sheet steel pre-painted low-rib profiles with steel supporting girts and purlins, and fibre-cement sheet on timber framing are the cheapest cladding systems for low-rise non-residential buildings in life cycle cost terms.

- In harsh environments the life cycle economics of other products, such as high performance factory-coated steel and concrete tilt slab and masonry claddings, become favourable.

- Formal techniques are available to include intangibles into the decision process on a logical and consistent basis. This inclusion can markedly change the preference order of materials from that given by a life cycle cost analysis alone.

- A carbon emission charge of up to $25 per tonne of Carbon Dioxide (CO_2), as announced by Government in April 2002, would increase the life cycle costs of some cladding systems by 3%; but for most claddings the increase will be less than this. Such a tax, aimed at reducing greenhouse gas emissions, will be introduced in 2007 as the Government has announced its intention to ratify the Kyoto Protocol. The actual carbon charge is not yet known, and will approximate the world trading price, but will be capped at $25 per tonne of CO_2 ($92 per tonne of Carbon).

2. INTRODUCTION

This study considers a number of issues relating to life cycle cost (LCC) analysis of building materials and is an extension of earlier work done on domestic claddings(1). The main result of the earlier work was that choosing material on the basis of lowest initial cost may not be the best choice as on-going maintenance costs often outweigh the savings in initial costs. That result generally holds true in the current study, where initial cost has been more broadly defined to include the costs of the cladding support structure.

LCC analysis allows for consistent cost comparisons to be made between materials with different life spans and different initial and maintenance costs. It allows for the time value of money in which future expenditures are discounted, compared to current expenditures. Further details of the technique are given in Appendix 1, and in references (2), (3)and (4). The variables that go into a life cycle cost analysis are initial cost, on-going maintenance costs, the timing of maintenance activities, the life span of the material until replacement, and the financial discount rate. The latter represents the time value of money and allows consistent comparisons to be made between options with different cash flows over time.

Users of non-residential buildings include both business and Government organisations, and tax issues need to be included for the former group. Appendix 1 describes how tax considerations (maintenance costs, interest payments, and depreciation), are included in the LCC analysis.

The main users of this report are expected to be designers and building owners of commercial and industrial buildings. The report provides data on initial and maintenance costs of claddings and their life cycle costs. Designers and owners will not choose a cladding made solely on the basis of initial or life cycle costs, as other factors such as aesthetics will also be important. This reports outlines ways to combine cost data with intangible factors such as aesthetics.

3. SCOPE

This report extends the earlier residential building LCC analysis to consider low-rise non-residential buildings, many of which have similar claddings to domestic buildings. However, while the large majority of domestic buildings are timber framed, non-residential low-rise buildings have a variety of structural systems and it is necessary to consider the cladding support system together with the cladding in order to make valid cost comparisons.

This report considers metal sheet claddings in some detail because metal claddings in both roof and walls are the predominant cladding type used in non-residential buildings. BRANZ surveys show that metal sheet claddings have an estimated market share of 35% of all wall claddings, and over 90% of roof claddings.

The earlier report(1) briefly discussed the relationship between costs and environmental conditions, and this report extends that analysis to consider a wider range of environments and materials.

Finally, some aspects of cladding selection, such as aesthetics and carbon taxes, are difficult to quantify and are usually omitted from the LCC analysis, but these often need to be included in the decision-making process. This report considers techniques for combining LCC results with these other factors.

In summary this report provides information in four main parts:

- An extension of the LCC analysis to cover commercial and industrial claddings, including the cladding support systems (though not the main structural frame).
- Some details of material and maintenance options in severe environments.
- The introduction of non-quantifiable factors into the analysis.
- The carbon tax implications for materials and a brief study of the potential cost effect of a carbon tax or, alternatively, of a carbon emissions trading regime.

4. RESULTS

4.1 Initial Cladding Cost Data

The initial cladding costs given in Figures 1 and 2 are broken down into cladding, cladding support and lining support costs. Two types of cladding support were examined: firstly, horizontal steel girts for walls, and steel purlins for roofs, spanning between the main portal frames. These were for the metal claddings. Secondly, a timber-framed wall with timber studs fixed to a steel top plate was used on smaller buildings for the fibre-cement and plywood wall claddings. In timber framing the wall frame supports both the cladding and the lining. However, with steel cladding and steel girts a timber infill frame is usually required to support the lining, where a lining is required. (It is acknowledged that many buildings, particularly industrial buildings, do not require linings).

The costs used in this report reflect market rates but they are indicative only and prices may vary due to regional differences and/or price competition on specific projects.

The claddings, cladding supports, and lining supports for walls are costed separately in Figure 1. The reason for the breakdown is to show the trade-off between the spanning capacity of the cladding and the support systems required. The data presented in Figure 1 is for a medium-sized building with 6m between the main portal frames, 6 m stud height, and portal span of 20 m. Some results are:

- Low-rib profile 0.40 mm steel sheet, 6 mm fibre-cement sheet and 12 mm plain plywood sheet have the lowest initial costs of cladding and support structures.

- Rib profile steel claddings cost more than the corrugated profile but have savings on the purlin/girt support structure.

- Textured finished 7.5 mm fibre-cement sheet cladding is expensive and has quite a high timber frame cost, but as this also acts as the lining framing there is some cost off-set.

- Tilt-slab cladding is expensive but as it doubles as the wall structure there are savings on framing. There are some additional foundation costs due to the heavy nature of the cladding and these are included. There may be additional earthquake restraint costs, and/or savings in the main frame (since the wall is able to take vertical loading), but these have not been included.

The results demonstrate that the wall and roof system needs to be considered as a whole when deriving initial costs for the life cycle cost analysis. Appendix 2 provides cost and structural analysis details.

4.2 Life Cycle Costs

The maintenance options and periods, and material life spans for claddings in a moderate environment, are shown in Table 1. They were derived in discussions with BRANZ durability scientists. They are estimates only and depend on a variety of factors including environment, condition of use, workmanship, etc. Life cycle costs are given in Tables 2 and 3, and Figures 3 and 4 for the materials commonly used on low-rise commercial/industrial buildings. These costs are given from a business perspective, i.e. they allow for tax deduction associated with maintenance, interest payments, and depreciation.

The main results are:

- Painted 6 mm fibre-cement sheet, on timber framing, is the cheapest wall cladding system of those considered.

- Pre-painted low-profile 0.40 mm steel cladding on steel girts is the next cheapest wall cladding system.

- Corrugated fibre-cement sheet, 150 mm thick concrete tilt slab, and concrete masonry block, are among the more expensive wall claddings.

- Unpainted 0.40 mm steel claddings, and steel purlins, are the cheapest roof cladding system. They are closely followed by unpainted 0.55 mm steel claddings, and 0.40 mm pre-painted steel.

Unpainted zinc/alumium coated steel surfaces are the cheapest roof option. However, they will eventually show surface rust and the appearance may not be acceptable. Therefore the lowest cost option would not necessarily be the best overall solution.

Costs are expressed in equivalent annual costs, which automatically compensates for the differing lifespan of materials. For a full discussion of the concept of annual costs see the earlier report(1). This reference describes the methodology, used here, which allows for consistent comparisons to be made between shorter life, low initial-cost materials, and longer life, high initial-cost materials. In brief, initial and on-going costs are spread over the life of the cladding, using the appropriate financial formulae, so that, for example, long-life tilt slab can be fairly compared with a short-life unpainted plywood cladding.

Note that the following indirect costs have not been included:

- Thermal insulation costs on-going heating costs been compared for the different designs. Timber-framed systems are likely to perform better than other systems, in this regard.

- The main structural frame costs have not been included and these may differ for the different cladding systems. For example tilt slab and concrete block systems provide in-plane bracing resistance while other claddings require additional bracing. They can also support vertical loads, which may reduce the main frame costs, compared to the more lightweight cladding systems.

- The concrete claddings provide inherent fire resistance while the other claddings may require additional fire-resistance measures, which would add to the cost.

For particular buildings these indirect costs may be significant and could change the ranking order of cladding types.

4.3 Sensitivity Analysis

Life cycle costs depend somewhat on the assumptions made. The most crucial parameter is the discount rate because this affects the trade-off between more durable materials with higher initial costs and low maintenance, as against lower cost materials with higher on-going maintenance costs, and shorter life spans. Figure 5 shows three selected cladding materials, with three different discount rates. At the low discount rate the on-going maintenance costs have a large influence in total life cycle costs, and the low maintenance costs of tilt slab gives the lowest life cycle cost of the three options. But at the high discount rate tilt slab's low maintenance is heavily discounted and does not offset its high initial cost, and vice versa for the other two materials. So in the latter situation the cheaper materials with high maintenance costs have lower life cycle costs.

In the bulk of this report an 8% discount rate was used. The reasons for this are given in Section 5.3.

Another parameter that was altered was the durability of the cladding material (see Figure 6). The change in life cycle costs due to change in life span is very small, indicating this parameter is not critical in life cycle cost analysis. This is because beyond about 25 years the change in discounted costs is quite small for normal discount rates.

The results in this report are given from the perspective of the business sector. However, a significant proportion of the building stock is publicly owned and tax considerations do not apply. In other words, the tax deduction for maintenance, interest cost and depreciation should not be included in the LCC analysis for non-business-owned buildings. When this is done the life cycle costs are significantly higher, by between 60% and 80%. The LCC rank order of wall cladding materials also changes slightly, with 6 mm fibre-cement dropping to number four in the ranking, and being replaced by unpainted 0.40 mm sheet steel at the top (see Table 4). For roof claddings the ranking of the various claddings is the same for business and non-business perspectives.

4.4 Claddings in Severe Environments

The types of cladding and maintenance regimes need to be tailored for the environment. Tables 5, 6, and 7, and Figure 7, show the analysis for selected claddings in severe and very severe industrial/marine environments, with data for the moderate environment provided for comparison. The environmental conditions are defined in Table 8. In this analysis the lining support costs have been omitted from the initial costs for simplicity, and because it is considered these harsh environments will mainly apply to unlined buildings such as industrial buildings. However it is acknowledged that significant numbers of commercial buildings will be in severe and very severe environments. The main results are:

- Steel claddings formulated for severe environments, such as polyester-coated steel and vinyl plastisol coatings, and uncoated aluminium sheet claddings, perform well from a life cycle cost perspective.

- The vinyl-plastisol-coated steel, which is specially formulated for very severe environments, and aluminium sheet, have the lowest life cycle costs of all claddings in this environment.

- Tilt slab performs well in terms of life cycle costs in the very severe environment.

4.5 Combination of the LCC Analysis with Intangible Decision Factors

Often costs are only one part of the decision-making process in material selection. Other factors such as aesthetics, impact resistance and fire resistance may be equally, or more, important than cost. It is sometimes difficult to quantify these factors, particularly aesthetics, which are often a matter of personal taste.

One technique used to combine LCC with difficult to quantify factors is the so-called Analytical Hierarchical Process (AHP) [(5)]. Full details of the technique are given in Appendix 3 but in brief, the process mixes quantifiable and non-numeric decision factors and asks for pairwise (or ranked) preferences to be made between all alternatives. The process allows for an individual's preferences of the relative importance of decision factors and how each material rates within each factor. Table 9 shows the results for three assessments on the non-residential claddings using LCC, aesthetics, cladding impact resistance and cladding fire resistance as the decision factors.

Trial 1 is for a building where cost and resistance to impact and fire damage is more important than appearance. This represents the average utilitarian industrial building. Concrete cladding materials are the preferred option (despite their fairly high cost) because of the high weighting given to impact and fire resistance in the AHP.

Trial 2 is for a showroom type building where appearance is very important and costs less important but still a consideration, while fire and impact resistance are relatively unimportant. In this case the stopped/high-build texture-coated fibre-cement sheet are the preferred options. These succeed because their appearance was rated highly by the decision-maker, and the weighting given to appearance overcame the high cost.

Trial 3 incorporates greenhouse gas effects and has equal weights in the AHP for costs and CO_2 emissions during manufacture of the cladding and girts/purlins. In brief, the plywood option is favoured because of its low CO_2 emissions. These AHP trials are discussed next.

4.6 Environmental Life Cycle Analysis (LCA) and LCC Analysis

Environmental LCA is concerned with the environmental impacts of materials throughout their life, through manufacture and use to disposal. One commonly used environmental impact is the material's energy use (embodied energy), which is a proxy for release of CO_2 emissions; however,costs are not usually an integral part of the LCA.

If embodied energy is to be included in the decision-making process when selecting a material, two possible methods could be used:

- Assume a carbon tax (of say $25 per tonne of CO_2) and calculate the initial and maintenance cost increases with this tax and re-calculate the life cycle costs.

- Use the AHP already described, with embodied energy for the cladding and support structure as an additional decision factor.

The details of the carbon tax approach are given in Appendix 4. The effects of a carbon tax were calculated for walls only, and the net effect on costs is comparatively small. The increase in initial costs (cladding and support structure) vary from a 4.6% increase for 0.9 mm hi-rib aluminium-clad walls to a 0.5% cost increase for plywood sheet/timber framing (see Appendix 4). The calculations are based on embodied energy of materials and expected changes in fuel costs used in the manufacture of the materials. Life cycle cost changes are equally small, as shown in Table 10 for wall cladding, with the 0.9 mm aluminium sheet cladding having the largest increase at 3.3%.

The second method used to include environment effects is the AHP. It has been demonstrated that environmental impacts can be quantified within a life cycle costs analysis if a carbon tax level is assumed. These cost changes can be used to rank the materials and then the environmental concerns can be reflected by an appropriate weight for this decision factor. The results for one set of weights are given in Table 9, under Trial 3, and show that when costs and CO2 emissions are equally weighted as very important then the preferred claddings are plywood sheet, and fibre-cement sheet. When ranked for life cycle costs alone plywood sheet cladding drops in ranking to number five.

5. DISCUSSION

5.1 Initial Costs

Many non-residential buildings, such as those used for educational, social, cultural and office/administration purposes have timber framing, similar cladding materials and the same scale of construction to housing, and are often located in the same areas as housing; therefore the earlier analysis(1) can be used. For example, fibre-cement sheet, brick veneer, EIFS, and timber weatherboard, with timber framing, are not uncommon wall-cladding materials in both housing and commercial buildings. However, industrial buildings and many low-rise commercial buildings have different claddings, they are larger than typical housing, are located in harsher environments than housing, and their economics will be different.

For example, most industrial buildings and many commercial buildings use steel wall claddings and concrete tilt slab, which are rare in housing. There is a range of steel profiles with different spanning capacities and any cost analysis based solely on the cladding would be misleading. Instead the cladding support structure and also the lining (if any) support system needs to be considered as well. For simplicity the analysis was restricted to cladding, cladding support and lining support costs. The main structural frame was ignored, and four sizes of commercial/industrial building were examined, as described in Appendix 2. These sizes were chosen in discussions with designers and are typical of the layouts actually used in practice.

The main finding on the initial costs was that for steel cladding the total cost (cladding, cladding support and lining supports) did not vary greatly between the corrugated, low-rib and high-rib profiles. The cladding cost varied by up to 23% between profiles, (excluding trough sections), but the system cost variation was typically less than 6%. This is encouraging for designers as it allows the profile to be selected for aesthetic of reasons without significant cost implications.

Another interesting finding was that the thinner steel and aluminium options were almost always cheaper than their thicker counterparts. This was confirmed by the suppliers who stated that more of the 0.40 mm steel and 0.70 mm aluminium sheets were sold than the heavier sheets, and that the latter were mainly used where there was a likelihood of damage due to frequent roof traffic, or a high risk of impact damage on wall claddings.

5.2 LCC of Claddings

The life cycle cost results are given in Tables 2 and 3. Steel claddings, and 6 mm fibre-cement sheet, are the cheapest in life cycle cost terms. As was found for the residential study, pre-painted steel profiles were cheaper than the zinc/aluminium coated steel/post-construction painted option. The near-flat steel profile was the cheapest overall option but it needs to be fixed to a solid sheet substrate to avoid deformation, and this sheet cost was not included in the analysis.

The analysis assumes that the life of the cladding and lining support is the same as the cladding itself. This is a simplification which may not apply in all cases. For example plywood cladding is replaced after 30 years (as per Table 2) but the timber framing would still be sound, as structural elements are required to have a 50-year durability under the New Zealand Building Code. However, the effect of this 'residual value' of the framing on life cycle costs is quite small.

The maintenance regimes used in the analysis are just one set of a number of regimes that could be used. This report uses a quite frequent maintenance option that maintains the building in a reasonable state of appearance. Another option, not considered here, is for low or zero maintenance. Often this regime is unacceptable, due to poor aesthetics, and also there are additional costs of disruption to building occupiers, due to more frequent replacement of claddings associated with zero-maintenance options.

5.3 Sensitivity Analysis

A discount rate of 8% was chosen as the default option in this report. It can be considered in two ways:

- It is a measure of the cost of capital to the building owner and is a real rate, i.e. the business borrowing rate, less the inflation rate.

- It is the rate of return that the business expects from its capital investment in the enterprise that is housed within the building. If the business uses its own money to construct the building, the rate of return on the building investment needs to be at least as high as the rest of the business. Most businesses aim to achieve at least an 8% real return on equity, though many don't achieve this.

On balance an 8% discount rate was considered appropriate for the analysis.

5.4 Claddings in Severe Environments

The specially formulated coatings (e.g. vinyl plastisol) on steel perform well in severe environments from a cost viewpoint, and uncoated aluminium and tilt slab also perform well.

The definitions of environmental conditions are given in Table 8, which gives a guide to the common environmental impacts on claddings. However, each building needs to be assessed for local conditions to determine the appropriate exposure environment. Table 8 should only be used as a guide because micro-climates may dictate alternative solutions.

5.5 Intangible Decision Factors

Incorporation of intangibles, such as aesthetics and impact resistance are shown in Table 9 for selected wall claddings. The analytical hierarchical process was used with three sets of weights given to the decision factors. It is readily apparent that the preferred cladding depends greatly on these weightings. The procedure allows the designer and owner to balance the decision variables, and to carry out sensitivity analysis by changing the weights. Ranking of materials under the various decision factors will also vary between people. There is no universal 'right' answer for selecting a cladding for a particular type of building or for an individual design. Different preferences may be revealed for different people using the process.

The advantage of the AHP is that it forces those people making the decisions to decide what the relevant decision variables are and to decide the relative weights given to each decision factor. It also forces them to explicitly rank materials under each factor. Ranking of materials is often quite easy because quantitative data is available to a greater or lesser degree of accuracy, i.e. LCC, resistance to impact, fire resistance, and environment emissions. It is the relative importance of these decision factors, and the ranking of materials on aesthetics, that are likely to cause most difficulty. As Table 9 indicates, when the weights are changed, the order of preference of the cladding changes. It is recommended that designers who want to use this procedure trial the process using two or three sets of decision factor of weights, to see if the preferred product changes. A simplified manual method for carrying out an AHP is set out in Appendix 3.

5.6 Environmental LCA and LCC

The incorporation of a carbon tax, or a carbon emissions trading regime, into the LCC analysis had a minor effect on costs. The maximum annual life cycle cost increase was estimated at 3.3%, for the 0.9 mm aluminium sheet wall, assuming a tax of $25 per tonne of CO_2. Plywood sheet claddings on timber framing have a comparatively low embodied energy content, and therefore their CO_2 emissions during manufacture are fairly low, and had only minor increases in costs.

The carbon content of materials was based on the work of Honey and Buchanan(6) and Alcorn(7). There are approximations in the embodied energy content of materials, uncertainty about the source of that energy (renewable or otherwise), and there has been subsequent restructuring of the manufacturing processes since the reports were written in 1992 and 2001, respectively. So therefore the calculations of carbon content are fairly approximate.

The level of the carbon tax is not known at this stage but will be no more than $25 per tonnes CO_2. Assuming Government proceeds as outlined in April 2002 (8) it is likely that company taxes could be reduced so that the impact on all business is tax neutral. However, the manufacture of building materials is more energy intensive than most business activities and likely to mean a net cost to manufacturers. Relative product prices may change to reflect the greater tax burden on the more energy-intensive building products, such as steel and aluminium. Note that aluminium smelting uses renewable hydro power (Manapouri) and the company, Comalco, may be able to persuade Government that it will be unfairly disadvantaged compared to overseas competitors. Hence the price rises mentioned in this report for aluminium may be significantly lower than stated.

The level of taxes has a proportional effect on life cycle costs, so that if the carbon tax was, say, $12.5 per tonne of CO_2 instead of the $25 per tonne of CO_2 used in the analysis, the increase in life cycle costs from the tax is halved. This assumes that production technologies remain unchanged but there are already moves by manufacturers, such as the cement and concrete industries, to voluntarily reduce their CO_2 emissions by using different technology, and fuel mix, and any future carbon tax is likely to accelerate this response. How this will affect production is unknown but manufacturers will seek to minimise their costs so that their selling price remains competitive.

The second method that includes greenhouse gas effects is the AHP. It has been demonstrated above that some environmental impacts can be quantified within a life cycle cost analysis if a carbon tax level is assumed. However, some owners may want to give greater weight to, environmental concerns than is implied by the small increases in costs associated with the likely proposed levels of carbon tax. In this case the AHP allows greater weight to be given to environmental impacts. Table 9, Trial 3, shows the results of this approach under one set of assumptions and indicates that consideration of environmental impacts in an AHP can significantly affect the ranking of materials.

6. CONCLUSIONS

- Cladding support costs need to be considered together with the cladding cost to enable consistent comparisons to be carried out on cladding systems.

- Pre-painted 0.40 mm thick sheet steel profiles (excluding the trough profile) and the steel purlin/ girt supports are among the cheapest cladding system for low-rise buildings in terms of life cycle costs. 12 mm plywood and 6mm fibre-cement, with plastic jointers, on timber framing are also among the cheapest cladding systems.

- In very severe environmental conditions vinyl plastisol-coated steel, uncoated aluminium and concrete tilt slab systems performed well in terms of life-cycle costs.

- The analytical hierarchy process (AHP) enables intangible, or difficult to quantify, factors to be included in the decision-making process so that these factors are explicitly considered, together with costs, and valid comparisons can be facilitated.

- When intangible factors such as aesthetics, impact resistance, and environmental impacts are included in an AHP, together with life-cycle costs, then the order of preference of materials can change from the order based on costs alone.

- With a hypothetical carbon tax of $25 per tonnes of CO_2 the worst affected system was 0.9 mm aluminium sheet cladding with an approximate 3.3% increase in life cycle costs in the moderate environment. However, the effect on life cycle costs with this level of tax was generally small and did not affect the ranking of materials in terms of costs.

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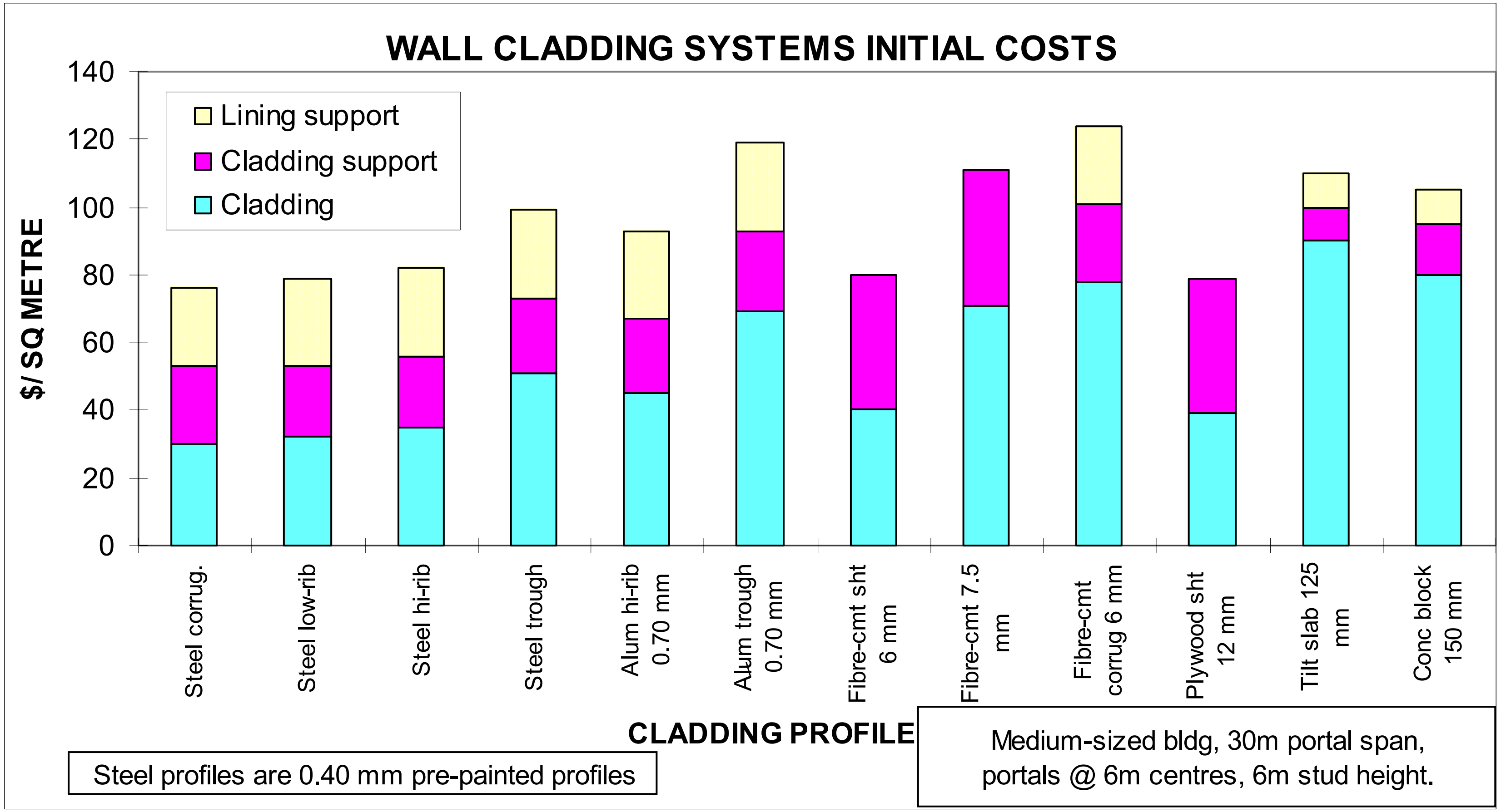


Figure 1. Wall cladding systems initial costs.

Note: In many buildings, such as industrial buildings, linings are not required, and linings costs could be omitted from the above chart.

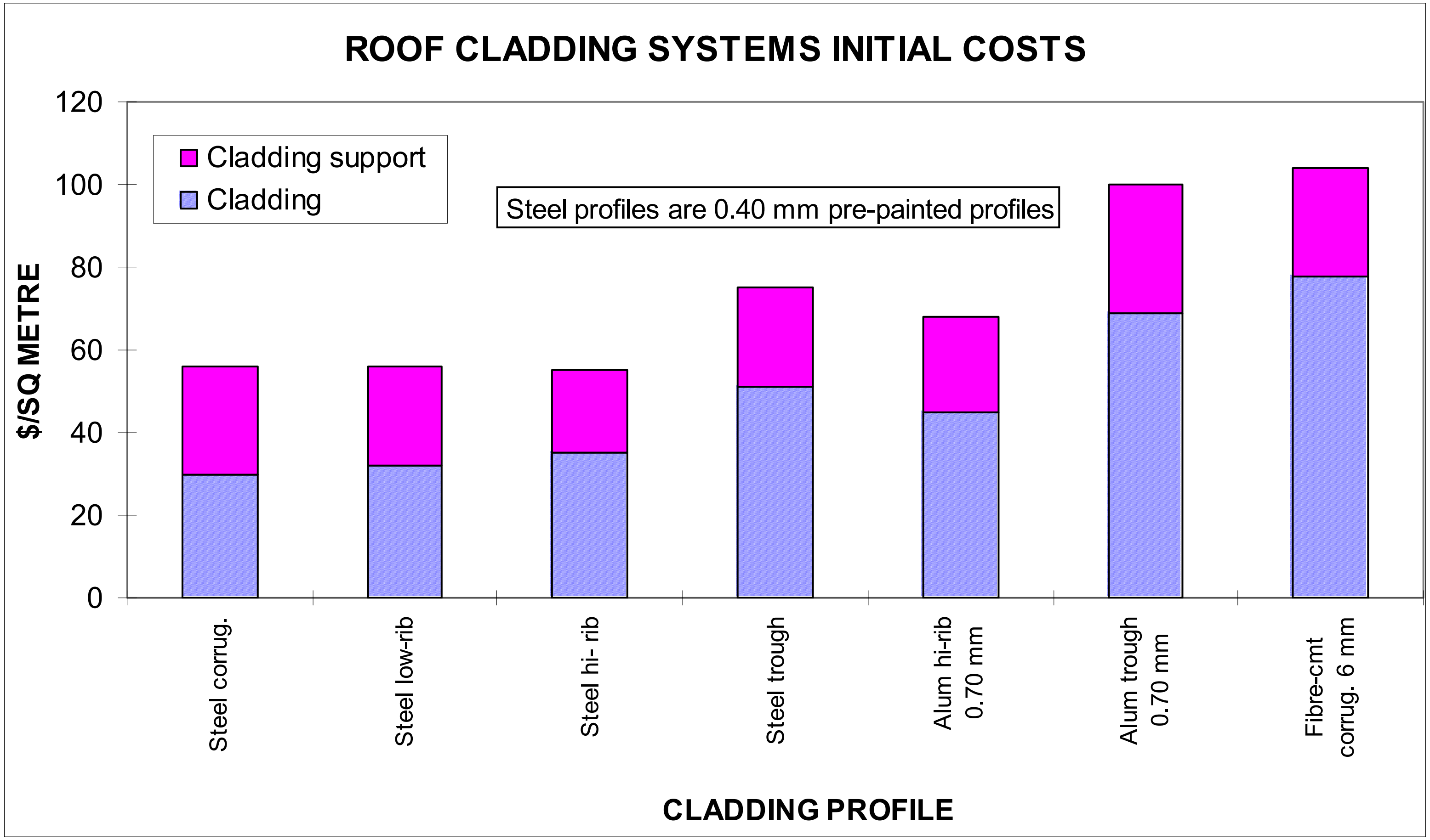

ROOF CLADDING SYSTEMS INITIAL COSTS
$/SQ METRE
120
100
80
60
40
20
0
Cladding support
Cladding
Steel profiles are 0.40 mm pre-painted profiles
Steel corrug.
Steel low-rib
Steel hi- rib
Steel trough
Alum hi-rib 0.70 mm
Alum trough 0.70 mm
Fibre-cmt corrug. 6 mm
CLADDING PROFILE

Figure 2. Roof cladding systems initial costs.

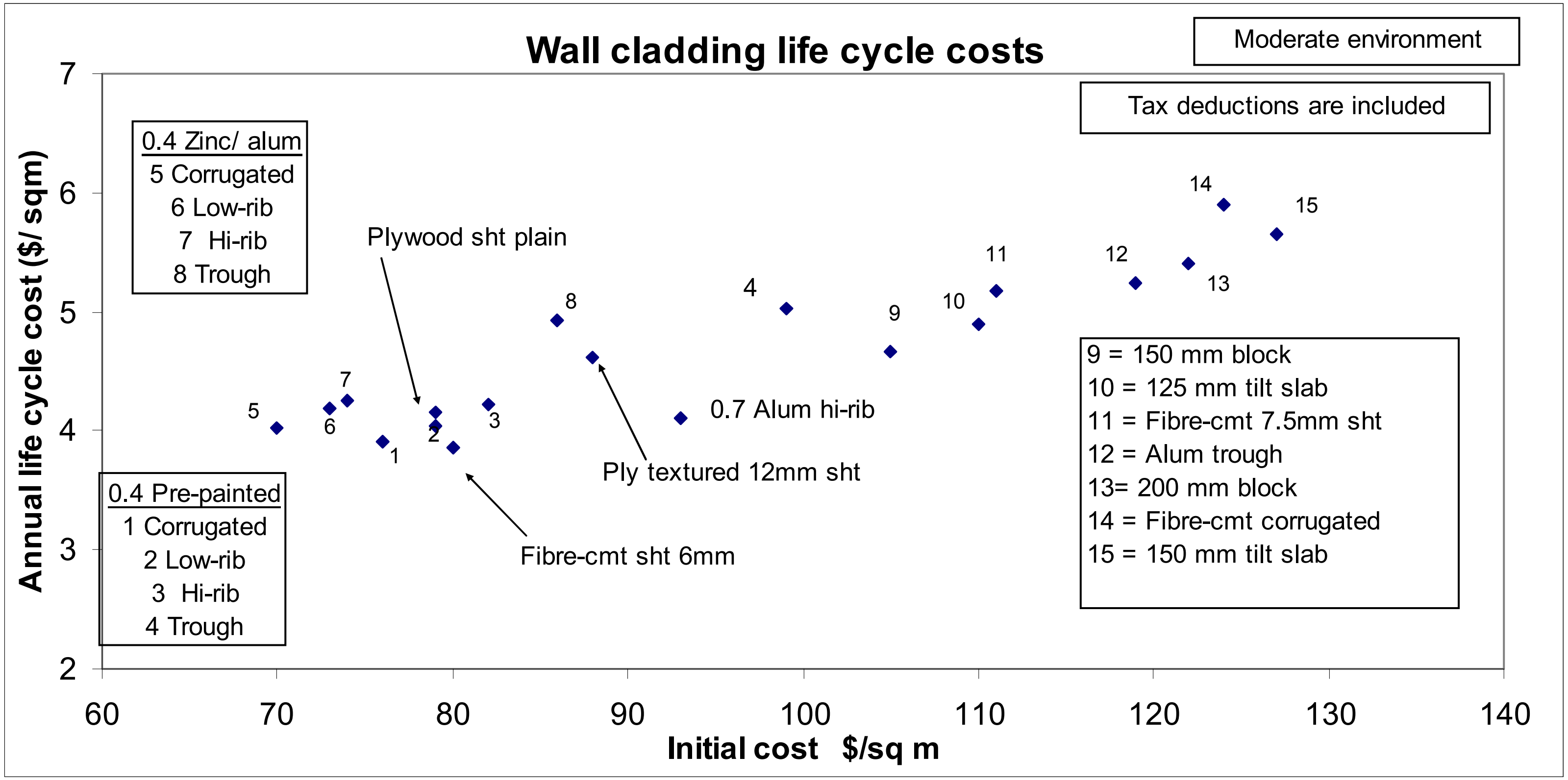


Figure 3. Wall cladding systems life cycle costs.

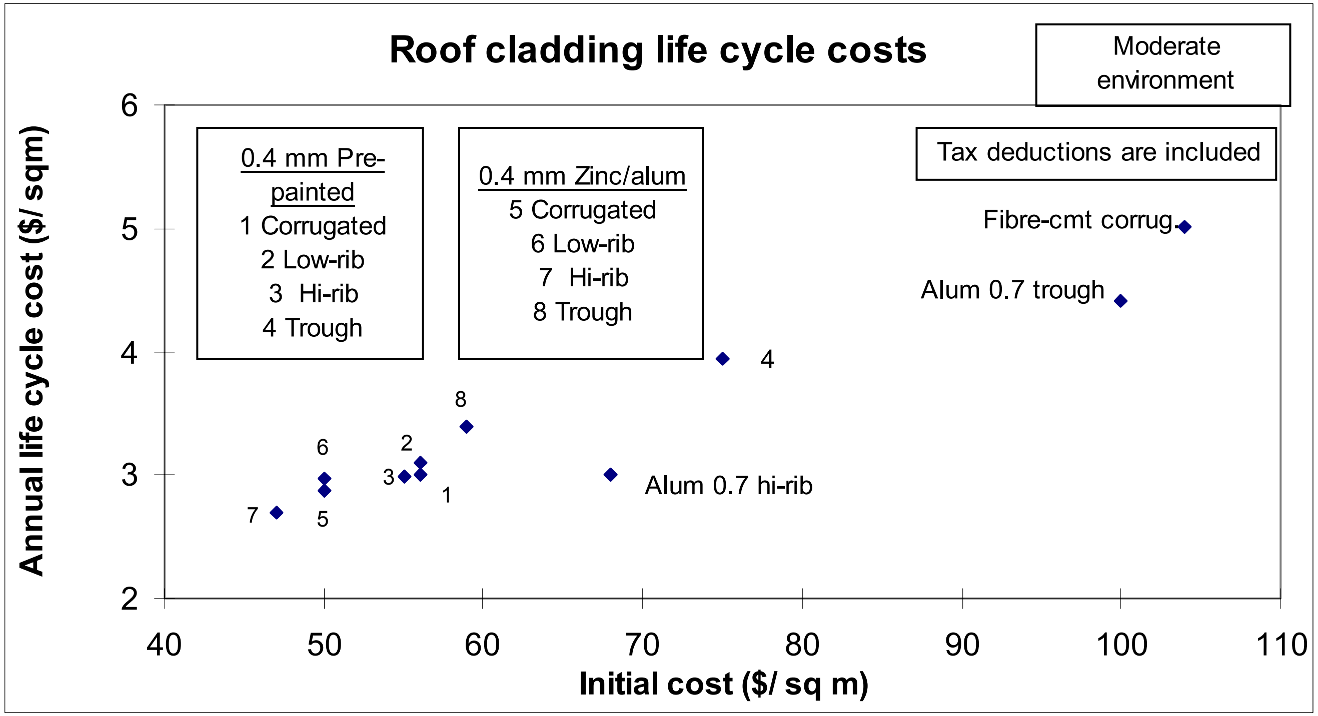


Figure 4. Roof cladding systems life cycle costs.

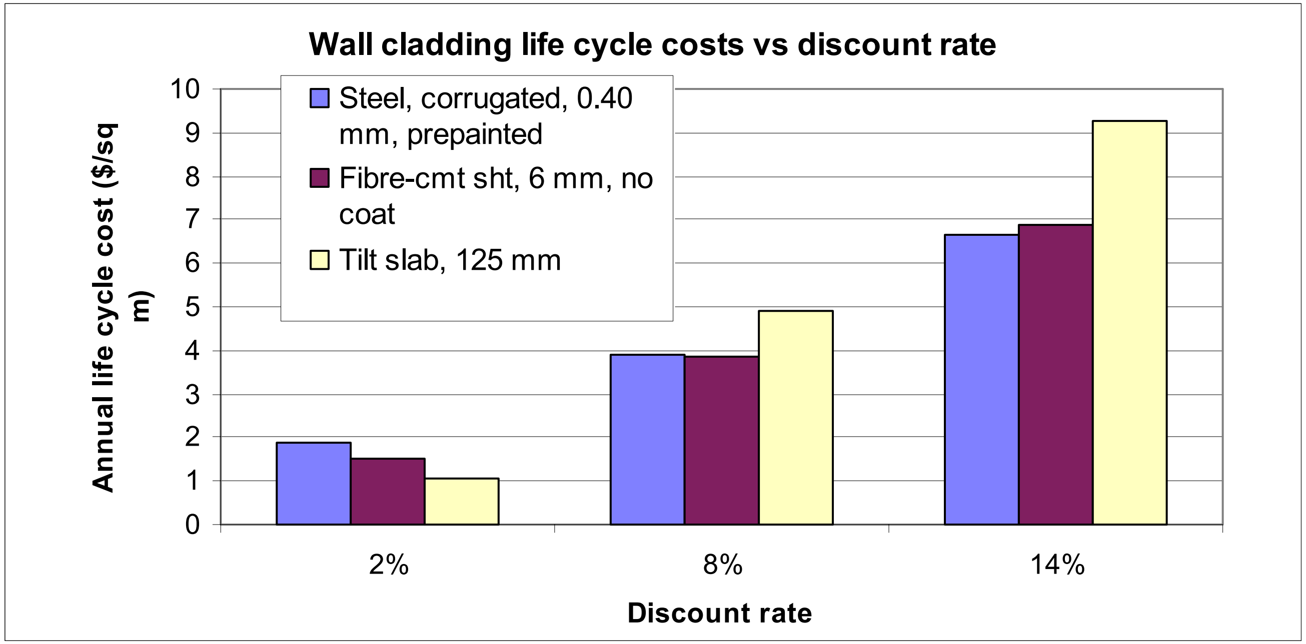


Figure 5. Life cycle costs vs discount rate.

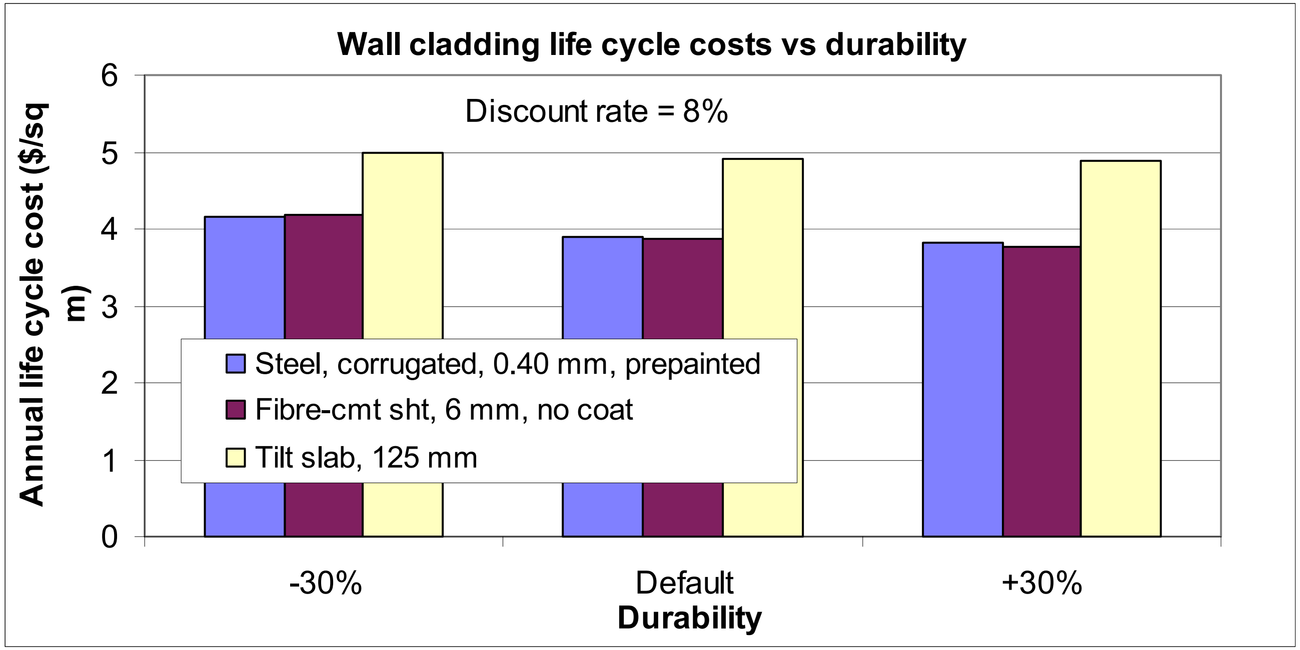


Figure 6. Life cycle costs v durability.

The default periods are 50 years for sheet steel and fibre-cement sheet, and 80 years for tilt slab.

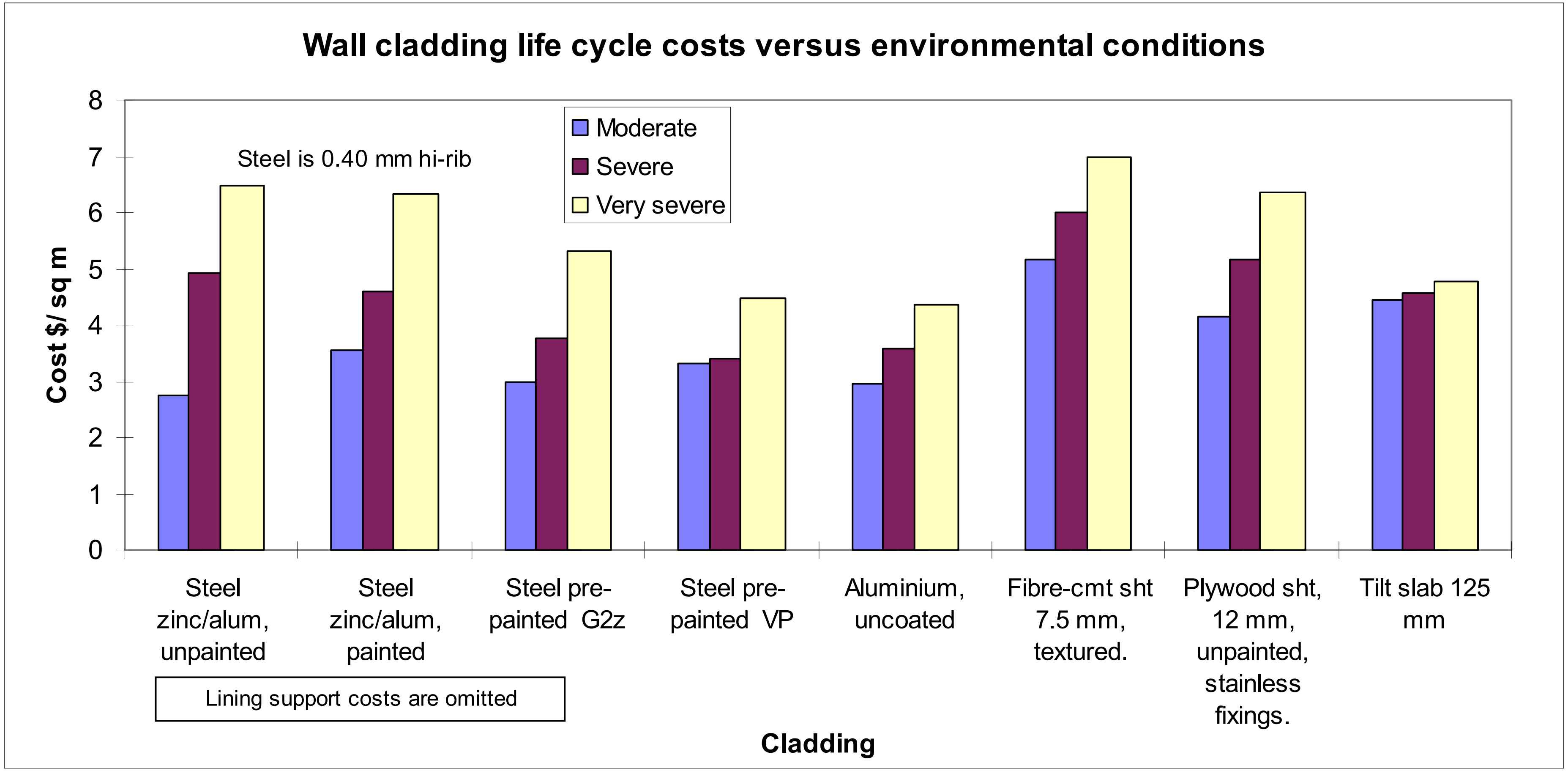


Figure7. Wall cladding systems annual life cycle costs vs environmental conditions.

Table 1. Cladding maintenance schedules.

Cladding maintenance schedules MODERATE ENVIRONMENT	
CLADDING	**TYPE OF WORK, MAINTENANCE INTERVAL AND LIFE SPAN**
Zinc/aluminium coated steel 0.40 mm & 0.55 mm.	Do not paint or maintain. Replace at 25 years.
Pre-painted zinc/alum coated steel 0.40 mm & 0.55 mm.	Repaint after 15 years, every 7 years thereafter. Water-blast clean at 35 years, continue repainting at 7-year intervals. Replace at 50 years.
Aluminium unpainted 0.70 mm & 0.90 mm.	Do not paint. Replace at 70 or 80 years.
Fibre-cement flat sheet 6.0 mm, PVC jointers, stainless nails.	Standard acrylic 3 coat initially, recoat every 10 years with 1 coat acrylic. Replace at 50 years.
Fibre-cement flat sheet 7.5 mm, stopped, texture coat.	High build acrylic 3 coat, fine texture initially, recoat every 10 years, after 10 years, with 1 coat acrylic. Replace at 60 years.
Fibre-cement corrugated sheet.	Do not paint. Chemical wash clean at 15 year intervals, replace at 40 years.
Plywood sheet, H3 treated, 12 mm. Plain. Stainless nails.	Do not paint. Replace at 30 years.
Plywood sheet, H3, 12 mm. Textured. Stainless nails.	Do not paint. Replace at 30 years.
Concrete tilt slab 125 mm and 150 mm.	No painting. Inspect/repair panel joints at 20-year intervals, replace wall at 80 years.
Concrete block masonry 150 mm and 200 mm block.	No painting. Inspect/repair pointing at 30 years. Replace wall at 80 years.

Table 2. Life cycle costs of wall cladding systems.

Life cycle costs of wall cladding systems — MODERATE ENVIRONMENT		Initial cost	LIFE	MAINTENANCE (COSTS IN $/SQM) 1		2		3		4		5		DISCOUNT RATE= 8% 1.08; TAX FACTOR = 0.67 Maintenance		Depreciatn & Interest	Initial	TOTAL
Wall cladding		$/sqm (1)	YRS	YR	CST	YR	CST	YR	CST	YR	CST	YR	CST	As a present value	As an annual cost	As an annual cost	As an annual cost	Annual cost
Steel 0.40 mm, zinc/aluminium, no coat																		
Corrugated	Steel girts	70	25											0.0	0.0	-2.5	6.6	4.02
Low-rib	Steel girts	73	25											0.0	0.0	-2.6	6.8	4.19
High-rib	Steel girts	74	25											0.0	0.0	-2.7	6.9	4.25
Trough	Steel girts	86	25											0.0	0.0	-3.1	8.1	4.93
Steel 0.40mm, zinc/alum, prepainted																		
Corrugated	Steel girts	76	50	15	12.0	22	11.0	29	11.0	36	14.0	42	11.0	8.3	0.5	-2.8	6.2	3.91
Low-rib	Steel girts	79	50	15	12.0	22	11.0	29	11.0	36	14.0	42	11.0	8.3	0.5	-2.9	6.5	4.04
High-rib	Steel girts	82	50	15	13.0	22	12.0	29	12.0	36	15.0	42	12.0	9.0	0.5	-3.0	6.7	4.22
Trough	Steel girts	99	50	15	14.0	22	13.0	29	13.0	36	16.0	42	13.0	9.7	0.5	-3.6	8.1	5.03
Steel 0.55mm, zinc/aluminium, no coat																		
Near flat	Steel girts	65	25											0.0	0.0	-2.4	6.1	3.73
Corrugated	Steel girts	71	25											0.0	0.0	-2.6	6.7	4.07
Low-rib	Steel girts	75	25											0.0	0.0	-2.7	7.0	4.30
High-rib	Steel girts	76	25											0.0	0.0	-2.8	7.1	4.36
Trough	Steel girts	85	25											0.0	0.0	-3.1	8.0	4.88
Steel 0.55mm, zinc/alum, prepainted																		
Near flat	Steel girts	70	50	15	12.0	22	11.0	29	11.0	36	14	42	11.0	8.3	0.5	-2.5	5.7	3.64
Corrugated	Steel girts	77	50	15	12.0	22	11.0	29	11.0	36	14	42	11.0	8.3	0.5	-2.8	6.3	3.95
Low-rib	Steel girts	81	50	15	12.0	22	11.0	29	11.0	36	14	42	11.0	8.3	0.5	-2.9	6.6	4.14
High-rib	Steel girts	84	50	15	13.0	22	12.0	29	12.0	36	15	42	12.0	9.0	0.5	-3.0	6.9	4.31
Trough	Steel girts	101	50	15	14.0	22	13.0	29	13.0	36	16	42	13.0	9.7	0.5	-3.7	8.3	5.12
Aluminium 0.70mm, no coat																		
High- rib	Steel girts	93	70											0.0	0.0	-3.4	7.5	4.10
Trough	Steel girts	119	70											0.0	0.0	-4.3	9.6	5.24
Aluminium 0.90mm, no coat																		
High- rib	Steel girts	95	80											0.0	0.0	-3.4	7.6	4.17
Trough	Steel girts	130	80											0.0	0.0	-4.7	10.4	5.70
Fibre-cement Flat Sheet, coated																		
6 mm PVC jointers	Timber frame	80	50	10	5.0	20	5.0	30	5.0	40	5.0			4.1	0.2	-2.9	6.5	3.86
7.5 mm textured coat	Timber frame	111	60	10	5.0	20	5.0	30	5.0	40	5.0	50	5.0	4.2	0.2	-4.0	9.0	5.17
Fibre-cement Corrugated Sheet, no coat																		
6mm corrugated	Steel girts	124	40											0.0	0.0	-4.5	10.4	5.90
Plywood sheet, 12 mm, H3 treated, no coat																		
Plain surface	Timber frame	79	30											0.0	0.0	-2.9	7.0	4.15
Sawn textured surface	Timber frame	88	30											0.0	0.0	-3.2	7.8	4.62
Concrete tilt slab, no coat.																		
125 mm thick	self supporting	110	80	20	5.0	40	5.0	60	5.0					1.4	0.1	-4.0	8.8	4.90
150 mm thick	self supporting	127	80	20	5.0	40	5.0	60	5.0					1.4	0.1	-4.6	10.2	5.64
Concrete block, no coat.																		
150 mm	self supporting	105	80	30	10.0	60	10							1.1	0.1	-3.8	8.4	4.67
200 mm	self supporting	122	80	30	10.0	60	10							1.1	0.1	-4.4	9.8	5.41

(1) Initial costs include the cladding and lining support, and initial paint coat on the non-prepainted steel claddings, and the initial coatings on the fibre-cement flat sheet. See Table 12.

Table 3. Life cycle costs of roof cladding systems.

Life cycle costs of roof cladding systems MODERATE ENVIRONMENT															DISCOUNT RATE= 8% TAX FACTOR = 0.67	1.08 Maintenance		Depreciatn & Interest	Initial	TOTAL
		Initial Cost	LIFE	MAINTENANCE (COSTS IN $/SQM) 1		2		3		4		5			8	As a present	As an annual	As an annual	As an annual	Annual
Roof cladding		(1)	YRS	YR	CST	YR	CST	YR	CST	YR	CST	YR	CST	CST	YR	value	cost	cost	cost	cost
Steel 0.40 mm, zinc/aluminium, no coat																				
Corrugated	Steel purlins	50	25													0.0	0.0	-1.8	4.7	2.87
Low-rib	Steel purlins	50	25													0.0	0.0	-1.8	4.7	2.87
High-rib	Steel purlins	47	25													0.0	0.0	-1.7	4.4	2.70
Trough	Steel purlins	59	25													0.0	0.0	-2.1	5.5	3.39
Steel 0.40 mm, zinc/alum, pre-painted																				
Corrugated	Steel purlins	56	50	15	12.0	22	11.0	29	11.0	36	14.0	42	11.0			8.3	0.5	-2.0	4.6	3.00
Low-rib	Steel purlins	56	50	15	12.0	22	11.0	29	11.0	36	14.0	42	11.0			8.3	0.5	-2.0	4.6	3.00
High-rib	Steel purlins	55	50	15	13.0	22	12.0	29	12.0	36	15.0	42	12.0			9.0	0.5	-2.0	4.5	2.99
Trough	Steel purlins	75	50	15	14.0	22	13.0	29	13.0	36	16.0	42	13.0			9.7	0.5	-2.7	6.1	3.94
Steel 0.55 mm, zinc/ aluminium, no coat																				
Corrugated	Steel purlins	50	25													0.0	0.0	-1.8	4.7	2.87
Low-rib	Steel purlins	52	25													0.0	0.0	-1.9	4.9	2.98
High-rib	Steel purlins	49	25													0.0	0.0	-1.8	4.6	2.81
Trough	Steel purlins	62	25													0.0	0.0	-2.3	5.8	3.56
Steel 0.55 mm, zinc/alum, pre-painted																				
Corrugated	Steel purlins	56	50	15	12.0	22	11.0	29	11.0	36	14.0	42	11.0			8.3	0.5	-2.0	4.6	3.00
Low-rib	Steel purlins	58	50	15	12.0	22	11.0	29	11.0	36	14.0	42	11.0			8.3	0.5	-2.1	4.7	3.09
High-rib	Steel purlins	57	50	15	13.0	22	12.0	29	12.0	36	15.0	42	12.0			9.0	0.5	-2.1	4.7	3.08
Trough	Steel purlins	78	50	15	14.0	22	13.0	29	13.0	36	16.0	42	13.0			9.7	0.5	-2.8	6.4	4.08
Fibre-cement corrugated sheet, no coat																				
	Steel purlins	104	40	15	3.0	30	3.0									1.2	0.1	-3.8	8.7	5.02
Aluminium 0.70 mm, no coat																				
High-rib	Steel purlins	68	70													0.0	0.0	-2.5	5.5	3.00
Trough	Steel purlins	100	70													0.0	0.0	-3.6	8.0	4.41
Aluminium 0.90 mm, no coat																				
High-rib	Steel purlins	69	80													0.0	0.0	-2.5	5.5	3.03
Trough	Steel purlins	105	80													0.0	0.0	-3.8	8.4	4.61

(1) Initial costs include the cladding support and initial paint coat on the non-pre-painted steel claddings. Depreciation is 3% per year SL method.

Table 4. LCC compared for business ownership and Government ownership.

Comparision of life cycle costs from a business and public ownership perspective			
Moderate environment	**Total annual LCC costs ($/sq m)**		
	Business	Public	%
Wall cladding	owned	owned	Increase
Steel 0.40 mm, zinc/aluminium coated, no paint			
Corrugated	4.02	6.56	63
Low-rib	4.19	6.84	63
High-rib	4.25	6.93	63
Trough	4.93	8.06	63
Steel 0.40 mm, zinc/alum, pre-painted			
Corrugated	3.91	6.89	76
Low-rib	4.04	7.14	76
High-rib	4.22	7.44	76
Trough	5.03	8.89	77
Steel 0.55 mm, zinc/aluminium coated, no paint			
Near flat	3.73	6.09	63
Corrugated	4.07	6.65	63
Low-rib	4.30	7.03	63
High-rib	4.36	7.12	63
Trough	4.88	7.96	63
Steel 0.55 mm, zinc/alum, pre-painted			
Near flat	3.64	6.40	76
Corrugated	3.95	6.97	76
Low-rib	4.14	7.30	77
High-rib	4.31	7.60	76
Trough	5.12	9.05	77
Aluminium 0.70 mm, no coat			
High-rib	4.10	7.47	82
Trough	5.24	9.56	82
Aluminium 0.90 mm, no coat			
High-rib	4.17	7.62	83
Trough	5.70	10.42	83
Fibre-cement flat sheet, coated			
6 mm PVC jointers	3.86	6.88	78
7.5 mm textured cc	5.17	9.31	80
Fibre-cement corrugated sheet, no coat			
6 mm corrugated	5.90	10.40	76
Plywood sheet, 12 mm, H3 treated, no coat			
Plain surface	4.15	7.02	69
Sawn textured surf	4.62	7.82	69
Concrete tilt slab, no coat			
125 mm thick	4.90	8.93	82
150 mm thick	5.64	10.29	82
Concrete block, no coat			
150 mm	4.67	8.51	82
200 mm	5.41	9.87	82

Table 5. Maintenance schedules and environmental conditions.

Maintenance schedules and the environment

Environment	WALL CLADDING		TYPE OF WORK, MAINTENANCE INTERVAL AND LIFE SPAN
Moderate environment (1)	Zinc/aluminium coated, unpainted		Do not paint. Replace after 25 years.
	Zinc/alum, post-painted		Paint on installation, repaint every 7 years. Blast clean at 35 years, repaint. Replace at 50 years.
	Pre-painted, zinc/ alum(2)	polyester	Repaint after 15 years, every 7 years thereafter. Blast clean at 35 years, continue repainting at 7 years. Replace at 50 years
	ditto	vinyl plastisol	As for polyester coat.
	Aluminium, no coating (3)		Do not paint. Replace at 70 years.
	7.5 mm Fibre-cement sheet		High build acrylic 3 coat, fine texture initially, recoat every 10 years with 1 coat acrylic. Replace at 60 years.
	12 mm Plywood sheet, plain		Do not paint. Replace at 30 years.
	125 mm tilt slab		No painting. Repair panel joints at 20 year intervals, replace at 80 years.
Severe	Zinc/aluminium coated, unpainted		Do not paint. Replace after 15 years. Wash rain sheltered areas twice a year.
	Zinc/alum, post- painted		Paint on installation, repaint every 6 years. Replace at 30 years. Wash rain-sheltered areas once a year.
	Pre-painted, zinc/ alum(2)	polyester	Repaint after 15 years, every 6 years thereafter. Wash rain-sheltered areas once a year. Replace at 35 years.
	ditto	vinyl plastisol	Repaint after 15 years, every 6 years thereafter. Replace at 45 years.
	Aluminium, no coating		Do not paint. Wash rain-sheltered areas once a year. Replace at 50 years.
	7.5 mm Fibre-cement sheet		High build acrylic 3 coat, fine texture initially, recoat every 8 years with 1 coat acrylic. Wash rain-sheltered areas once a year. Replace at 50 years.
	12 mm Plywood sheet, plain		Do not paint. Replace at 20 years.
	125 mm tilt slab		No painting. Repair panel joints at 15 year intervals, replace at 60 years.
Very severe	Zinc/aluminium coated, unpainted		Do not paint. Replace after 10 years. Wash rain sheltered areas twice a year.
	Zinc/alum, post- painted		Paint on installation, repaint every 4 years. Replace at 20 years. Wash rain-sheltered areas twice a year.
	Pre-painted, zinc/ alum(2)	polyester	Repaint after 12 years, then every 4 years thereafter. Wash rain-sheltered areas twice a year. Replace at 25 years.
	ditto	vinyl plastisol	Repaint after 8 years, then every 4 years thereafter. Wash rain-sheltered areas once a year. Replace at 35 years
	Aluminium, no coating		Do not paint. Wash rain-sheltered areas twice a year. Replace at 35 years.
	7.5 mm Fibre-cement sheet		High build 3 coat acrylic at installation. Repaint every 5 years with 1 coat acrylic. Wash rain sheltered areas twice a year. Replace at 40 years.
	12 mm Plywood sheet, plain		Do not paint. Replace at 15 years.
	125 mm tilt slab		Do not paint. Repair panel joints every 10 years. Replace at 50 years.
	ROOF CLADDING		
Moderate environment	Zinc/aluminium coated, unpainted		Do not paint. Replace after 25 years.
	Zinc/alum, post- painted		Paint on installation, repaint every 7 years. Blast clean at 35 years, repaint. Replace at 50 years.
	Pre-painted, zinc/ alum(2)	polyester	Repaint after 15 years, every 7 years thereafter. Blast clean at 40 years, continue repainting at 7 years. Replace at 50 years.
	ditto	vinyl plastisol	As for G2z.
	Aluminium, no coating		Do not paint. Replace at 70 years.
	Fibre-cement corrugated sheet		Do not paint. Water-blast at 15 year intervals, replace at 40 years.
Severe	Zinc/aluminium coated, unpainted		Do not paint. Replace after 15 years.
	Zinc/alum, post- painted		Paint on installation, repaint every 6 years. Replace at 30 years.
	Pre-painted, zinc/ alum(2)	polyester	Repaint after 15 years, every 6 years thereafter. Replace at 35 years.
	ditto	vinyl plastisol	Repaint after 15 years, every 6 years thereafter. Replace at 45 years.
	Aluminium, no coating		Do not paint. Replace at 50 years.
	Fibre-cement corrugated sheet		Do not paint. Water-blast at 12 year intervals, replace at 35 years.
Very severe	Zinc/aluminium coated, unpainted		Do not paint. Replace after 10 years.
	Zinc/alum, post- painted		Paint on installation, repaint every 4 years. Replace at 20 years.
	Pre-painted, zinc/ alum(2)	polyester	Repaint after 12 years, then every 4 years thereafter. Replace at 25 years
	ditto	vinyl plastisol	Repaint after 8 years, then every 4 years thereafter. Replace at 35 years.
	Aluminium, no coating		Do not paint. Replace at 35 years.
	Fibre-cement corrugated sheet		Do not paint. Water-blast clean every 10 years. Replace at 30 years.

(1) Environments as defined by BHP NZ Steel Ltd brochure - "Environmental Categories."
(2) Steel cladding profile is high-rib profile 0.40 mm BMT.
(3) Aluminium cladding profile is high-rib profile 0.70 mm BMT.

Table 6. Life cycle costs and the environment for wall cladding systems.

Life cycle costs and the environment for wall claddings

DISCOUNT RATE= 8% | TAX FACTOR = 0.67 | Depreciatn & 1.08

Environment (4)	WALL CLADDING	Initial cost ($/sq m) (1)	Life (Yrs)	MAINTENANCE (COSTS IN $/SQ M) 1 YR	1 CST	2 YR	2 CST	3 YR	3 CST	4 YR	4 CST	5 YR	5 CST	6 YR	6 CST	7 YR	7 CST	8 YR	8 CST	9 YR	9 CST	10 YR	10 CST	Maintenance As a present value	Maintenance As an annual cost	Interest As an annual cost	Initial As an annual cost	Total Annual cost
Moderate	Zinc/aluminium coated, unpainted	48	25																					0.0	0.0	-1.7	4.5	2.8
	Zinc/alum, post-painted	60	50	7	11.0	14	11.0	21	11.0	28	11.0	35	14.0	42	11.0									15.0	0.8	-2.2	4.9	3.5
	Pre-painted, zinc/ alum(2) polyester	56	50	15	12.0	22	11.0	29	11.0	36	14.0	43	11.0											8.3	0.5	-2.0	4.6	3.0
	ditto vinyl plastisol	63	50	15	12.0	22	11.0	29	11.0	36	14.0	43	11.0											8.3	0.5	-2.3	5.1	3.3
	Aluminium, no coating (3)	67	70																					0.0	0.0	-2.4	5.4	3.0
	7.5 mm Fibre-cmt sheet	111	60	10	5.0	20	5.0	30	5.0	40	5.0	50	5.0											4.2	0.2	-4.0	9.0	5.2
	12 mm Plywood sheet, plain	79	30																					0.0	0.0	-2.9	7.0	4.1
	125 mm concrete tilt slab	100	80	20	5.0	40	5.0	60	5.0															1.4	0.1	-3.6	8.0	4.5
Severe	Zinc/aluminium coated, unpainted	48	15	3	8.0	8	8.0	13	8.0															13.6	1.1	-1.7	5.6	4.9
	Zinc/alum, post-painted	60	30	6	11.0	12	11.0	18	11.0	24	11.0	3	4.0	8	4.0	13	4.0	18	4.0	23	4.0			24.3	1.4	-2.2	5.3	4.6
	Pre-painted, zinc/ alum(2) polyester	56	35	15	12.0	21	11.0	27	11.0	33	11.0	3	4.0	8	4.0	13	4.0	18	4.0	23	4.0	33	8.0	17.3	1.0	-2.0	4.8	3.8
	ditto vinyl plastisol	63	45	15	12.0	21	11.0	27	11.0	33	11.0	39	11.0											8.8	0.5	-2.3	5.2	3.4
	Aluminium, no coating	67	50	3	4.0	8	4.0	13	4.0	18	4.0	23	4.0	28	4.0	33	4.0	38	4.0	43	4.0			9.6	0.5	-2.4	5.5	3.6
	7.5 mm Fibre-cmt sheet	111	50	8	5.0	16	5.0	24	5.0	32	5.0	40	5.0	48	5.0	3	4.0	8	4.0	13	4.0	23	28.0	17.3	0.9	-4.0	9.1	6.0
	12 mm Plywood sheet, plain	79	20																					0.0	0.0	-2.9	8.0	5.2
	125 mm concrete tilt slab	100	60	15	5.0	30	5.0	45	5.0															2.2	0.1	-3.6	8.1	4.6
Very severe	Zinc/aluminium coated, unpainted	48	10	3	8.0	8	8.0																	10.7	1.1	-1.7	7.2	6.5
	Zinc/alum, post-painted	60	20	4	11.0	8	11.0	12	11.0	16	11.0	3	8.0	8	8.0	13	8.0							35.2	2.4	-2.2	6.1	6.3
	Pre-painted, zinc/ alum(2) polyester	56	25	8	12.0	12	11.0	16	11.0	20	11.0	3	8.0	8	8.0	13	8.0	18	8.0	23	8.0			33.4	2.1	-2.0	5.2	5.3
	ditto vinyl plastisol	63	35	12	12.0	16	11.0	20	11.0	24	11.0	28	11.0	32	11.0	3	4.0	8	4.0	13	4.0	23	16.0	23.8	1.4	-2.3	5.4	4.5
	Aluminium, no coating	67	35	3	8.0	8	8.0	13	8.0	18	8.0	23	8.0	28	8.0									17.9	1.0	-2.4	5.7	4.3
	7.5 mm Fibre-cmt sheet	111	40	5	5.0	10	5.0	15	5.0	20	5.0	25	5.0	33	10.0	3	8.0	8	8.0	13	8.0	23	40.0	30.3	1.7	-4.0	9.3	7.0
	12 mm Plywood sheet, plain	79	15																					0.0	0.0	-2.9	9.2	6.4
	125 mm concrete tilt slab	100	50	10	5.0	20	5.0	30	5.0	40	5.0													4.1	0.2	-3.6	8.2	4.8

(1) Initial costs include the cladding and cladding support only, lining support is omitted. Costs are for a medium-sized building.
(2) Steel cladding profile is high-rib 0.40mm BMT.
(3) Aluminium cladding profile is high-rib 0.70mm BMT.
(4) Environmental conditions are defined in Table 7.
[box] = Washing down costs for areas not washed by rainwater.

Table 7. Life cycle costs and the environment for roof cladding systems.

Life cycle costs and the environment for roof claddings

DISCOUNT RATE= 8% | TAX FACTOR 0.67 | Depreciatn & 1.08

Environment (4)	ROOF CLADDING	Initial cost ($/sq m)	Life (Yrs)	MAINTENANCE (COSTS IN $/SQ M) 1 YR	1 CST	2 YR	2 CST	3 YR	3 CST	4 YR	4 CST	5 YR	5 CST	6 YR	6 CST	7 YR	7 CST	8 YR	8 CST	9 YR	9 CST	10 YR	10 CST	Maintenance As a present value	Maintenance As an annual cost	Depreciatn & Interest As an annual cost	Initial As an annual cost	Total Annual cost
Moderate	Zinc/aluminium coated, unpainted	47	25																					0.0	0.0	-1.7	4.4	2.7
	Zinc/alum, post-painted	59	50	7	11.0	14	11.0	21	11.0	28	11.0	35	14.0	42	11.0									15.0	0.8	-2.1	4.8	3.5
	Pre-painted, zinc/ alum(2) polyester	55	50	15	12.0	22	11.0	29	11.0	36	14.0	43	11.0											8.3	0.5	-2.0	4.5	3.0
	ditto vinyl plastisol	62	50	15	12.0	22	11.0	29	11.0	36	14.0	43	11.0											8.3	0.5	-2.3	5.1	3.3
	Aluminium, no coating	68	70																					0.0	0.0	-2.5	5.5	3.0
	Fibre-cement corrugated sheet	104	40	15	3.0	30	3.0																	1.2	0.1	-3.8	8.7	5.0
Severe	Zinc/aluminium coated, unpainted	47	15																					0.0	0.0	-1.7	5.5	3.8
	Zinc/alum, post-painted	59	30	6	11.0	12	11.0	18	11.0	24	11.0													15.8	0.9	-2.1	5.2	4.0
	Pre-painted, zinc/ alum(2) polyester	55	35	15	12.0	21	11.0	27	11.0	33	11.0													8.2	0.5	-2.0	4.7	3.2
	ditto vinyl plastisol	62	45	15	12.0	21	11.0	27	11.0	33	11.0	39	11.0											8.8	0.5	-2.3	5.1	3.4
	Aluminium, no coating	68	50																					0.0	0.0	-2.5	5.6	3.1
	Fibre-cement corrugated sheet	104	35	12	3.0	24	3.0																	1.7	0.1	-3.8	8.9	5.2
Very severe	Zinc/aluminium coated, unpainted	47	10																					0.0	0.0	-1.7	7.0	5.3
	Zinc/alum, post-painted	59	20	4	11.0	8	11.0	12	11.0	16	11.0													21.6	1.5	-2.1	6.0	5.3
	Pre-painted, zinc/ alum(2) polyester	55	25	8	12.0	12	11.0	16	11.0	20	11.0													16.4	1.0	-2.0	5.2	4.2
	ditto vinyl plastisol	62	35	12	12.0	16	11.0	20	11.0	24	11.0	28	11.0	32	11.0									14.3	0.8	-2.3	5.3	3.9
	Aluminium, no coating	68	35																					0.0	0.0	-2.5	5.8	3.4
	Fibre-cement corrugated sheet	104	30	10	3.0	20	3.0																	2.0	0.1	-3.8	9.2	5.6

(1) Initial costs include the cladding and cladding support. Costs are for a medium-sized building.
(2) Steel cladding profile is high rib 0.40 mm BMT.
(3) Aluminium cladding profile is high rib 0.70 mm BMT.
(4) Environmental conditions are defined in Table 7.
[ ] = Washing down costs for areas not washed by rainwater.

Table 8. Environmental condition definitions.

Environmental condition definitions		
Environment	**Characteristics**	
	Coastal areas	**Industrial areas**
Moderate environment	Little or no salt deposits. Typically at least 500 metres from breaking surf on exposed coasts. In the immediate vicinity of calm salt water such as estuaries and harbours.	Industrial odours only occasionally. Typically at least 250 metres from industrial emissions.
Severe environment	Light salt deposits. Typically 100 to 500 metres from breaking surf on exposed coasts. This environment may extend inland by prevailing winds.	A frequent smell of industrial chemicals in the air. Typically 100 to 250 metres from corrosive industrial emissions.
Very severe environment	Heavy salt deposits. Typically 0 to 100 metres from breaking surf on exposed coasts. This environment may extend inland with prevailing winds.	Continuous smell of industrial chemicals such as sulphur or acid in the air. Typically 0 to 100 metres from corrosive industrial emissions and subject to heavy fallout from them.
The environment classifications are based on the BHP NZ Steel publication "Environmental Categories".		

Table 9. Incorporating intangible factors with costs.

Incorporating intangible factors with cost

Selected wall claddings	LCC (1) Ranking (2)	AHP (3) Trial 1 (Robust building) Ranking	AHP Trial 2 (Aesthetics important) Ranking	AHP Trial 3 (Low CO2 emissions) Ranking
Steel 0.40 mm, zinc/ alum, pre-painted				
Corrugated	2	3	3	4
Low-rib	3	5	5	6
High-rib	6	4	4	5
Aluminium 0.70 mm, no coat				
High-rib	4	7	7	8
Fibre-cement sheet 7.5 mm				
PVC jointers	1	9	8	3
Stopped / textured	8	8	1	2
Plywood sheet, 12 mm, H3 treated				
Plain	5	6	6	1
Concrete tilt slab				
125 mm thick	7	1	2	7
Concrete block				
200 mm	9	2	9	9

(1) LCC = Life cycle costs.
(2) Ranking 1 = most favourable cladding, 9 = least favourable cladding.
(3) AHP = Analytical hieratical process. See text.
AHP trials are based on the following decision variables and weightings:

	LCC	Aesthetics	Impact resistance	Fire resistance	CO2 emissions
Trial 1	5	1	4	3	NA
Trial 2	3	5	2	1	NA
Trial 3	5	3	1	2	5

where the weighting scale ranges from 5= Very important
1= Not important

Table 10. Carbon tax effects on wall life cycle costs.

Carbon tax effect on life cycle costs			
MODERATE ENVIRONMENT		Discount rate = 8%.	
	Additional initial cost (1) $/Sq m	Carbon taxed LCC (2) $/Sqm	% change in LCC (3)
Steel 0.40 mm, zinc/ alum, unpainted			
Corrugated	0.99	4.07	1.4
Low-rib	0.92	4.24	1.3
High-rib	0.94	4.30	1.3
Trough	1.04	4.99	1.2
Steel 0.40 mm, zinc/alum, pre-painted			
Corrugated	1.02	3.96	1.2
Low-rib	0.95	4.09	1.1
High-rib	0.98	4.26	1.1
Trough	1.08	5.08	1.0
Steel 0.55 mm, zinc/ alum, unpainted			
Near flat	1.08	3.79	1.7
Corrugated	1.09	4.14	1.5
Low-rib	1.10	4.37	1.5
High-rib	1.16	4.43	1.5
Trough	1.29	4.95	1.5
Steel 0.55 mm, zinc/ alum, pre-painted			
Near flat	1.11	3.69	1.4
Corrugated	1.12	4.01	1.3
Low-rib	1.13	4.19	1.3
High-rib	1.20	4.37	1.3
Trough	1.33	5.18	1.2
Aluminium 0.70 mm, no coat			
High-rib	2.59	4.21	2.8
Trough	2.83	5.37	2.4
Aluminium 0.90 mm, no coat			
High-rib	3.18	4.31	3.3
Trough	3.52	5.86	2.7
Fibre-cement flat sheet, coated			
6 mm PVC jointers	0.52	3.89	0.6
7.5 mm Stopped	0.65	5.20	0.6
Fibre-cement corrugated sheet, no coat			
6 mm corrugated	0.00	5.94	0.7
Plywood sheet, 12 mm, H3 treated, no coat			
Plain surface	0.00	4.17	0.5
Textured surface	0.00	4.64	0.4
Concrete tilt slab, no coat			
125 mm thick	1.45	4.96	1.3
150 mm thick	1.71	5.72	1.3
Concrete block, no coat			
150 mm	1.20	4.72	1.1
200 mm	1.55	5.48	1.3

(1) Additions in the initial cost due to $50 per tonne carbon tax.
(2) Includes carbon tax on maintenance and initial (cladding + support) costs.
(3) % change in LCC is change from the untaxed LCC.

APPENDIX 1: LIFE CYCLE COST ANALYSIS

The principles of life cycle cost analysis are well known, and suitable texts for further information are listed in references [2], [3] and [4]. In brief, the technique involves the idea that a $1 expenditure now costs more than if it were deferred, say five years into the future. Whereas in the first case $1 is needed now, in the second case a lesser amount can be set aside now to earn interest so that it amounts to $1 in five years' time. The amount to set aside now is that which, when compounded at the appropriate interest rate (or discount rate), will exactly equal $1 in five years' time. The compound factor is given by:

$(1 + r)^5 = 1.611$ for r=10%.

Therefore, the amount to be set aside now is only $1/1.611 = 62 cents. Or, in other words, an expenditure of $1 in five years' time is only worth 62 cents in today's values.

The technique used in this study is to bring all costs to present values and then to spread these costs annually across the life of the material. The relevant formulae are:

$$PV = P + C_1 / (1+ r) + C_2 /(1+r)^2 + C_3 /(1+r)^3 + \quad + C_N /(1+r)^N \qquad \text{Equation 1.}$$

where PV = present value of the future cost streams $/sq metres.

P = Initial cost of material $/sq metres.

C_1 , C_2 , C_3 C_N = after tax maintenance costs, $/sqm, in year 1, 2, 3...... N.

r = discount rate.

N = life of material.

Hence

$$PV = P + \sum C_i/(1+r)^t \qquad \text{Equation 2.}$$

A business's building maintenance costs, interest payments and depreciation are tax deductable. It can be shown that Equation 2 then becomes:

$$PV = P + 0.67*\sum C_i/(1+r)^t - 0.33*\sum P*r/(1+r)^t - 0.33*\sum P*0.03/(1+r)^t \qquad \text{Equation 3.}$$

The second term in Equation 3 is the after-tax maintenance costs. The third term in Equation 3 shows interest payment tax deductions, and the last term is the depreciation allowance, assume straight-line depreciation at 3% per year (rather than dimishing value depreciation), for simplicity.

The present value is then spread over the life of the material, as an equivalent annual cost, using the following formula:

$$A = PV * CRF(r/N) \qquad \text{Equation 4.}$$

where A = annual equivalent life cycle cost $/sqm

CRF(r/N) = Capital recovery factor for N years and discount rate r,

$$CRF(r/N) = r(1+r)^N/((1+r)^N-1) \qquad \text{Equation 5.}$$

This equivalent annual cost is similar in concept to mortgage repayments, because maintenance has been brought to present-day values (equivalent to an amount borrowed) and is then spread in equivalent annual costs (or mortgage repayments) over the life of the material.

The discount rate is an important factor affecting the relative advantage of low-maintenance, high-cost materials, against high-maintenance, low-cost materials. For non-residential buildings the relevant rate is the after-tax rate of return that the business earns. If the real rate is used (i.e. the nominal rate less expected inflation) then the effect of inflation on future maintenance costs can be ignored. For the purposes of this study the business after-tax rate of return is assumed to be around 11%. If inflation at 3% is deducted then the long term real rate of return is around 8%.

The maintenance regimes included in the study are given in Tables 1 and the life cycle costs in Tables 2 and 3. The maintenance unit rates are given in Table 10. These are actual costs, 33% of which are tax deductible.

Table 11. Painting and repair costs.

Painting and repair costs	
PAINT WALL	$/Sq m
Zinc/alum steel corrugated/low-rib: Primer - 2 coats acrylic	12.0
Zinc/alum steel high-rib: Primer + 2 coats acrylic	13.0
Zinc/alum steel trough section: Primer + 2 coats acrylic	14.0
Steel corrugated/low-rib: Clean, repaint 2 coats acrylic	11.0
Steel trough high-rib: Clean, repaint 2 coats acrylic	12.0
Steel trough section: Clean, repaint 2 coats acrylic	13.0
Fibre-cement sheet 7.5 mm:- Jointing/flushing	8.0
Fibre-cement sheet 7.5 mm:- High build 3 coats acrylic, textured	26.0
Fibre-cement sheet:- Repaint, 1 coat acrylic	5.0
Fibre-cement sheet 6 mm: Primer + 2 coats acrylic	11.0
Repair joints in tilt slab	5.0
Repair pointing in concrete block	10.0
PAINT ROOF	
Steel profiles as for walls	
Waterblast cleaning	3.0
Cost base year 2001/2002.	

APPENDIX 2: STRUCTURAL SUPPORT SYSTEMS FOR CLADDINGS AND LININGS

This appendix outlines the structural support systems used to obtain the initial costs of the different cladding systems. It is important to consider the structural system costs as well as the cladding costs since the spanning capacity of claddings varies significantly, particularly among the various steel profiles.

Table 12 shows the summary of results of initial costs of the claddings and supports. For the steel cladding there is a trade-off between cladding cost and spanning capability and costs of purlins/girts. In general the low-rib profiles have the lowest overall initial costs. Trough section steel cladding is expensive due to its large surface area compared to the other profiles, and has a fairly low spanning capacity and hence is the most expensive system among the steel options. Many industrial buildings will not require linings but commercial and institutional buildings generally will, and in these cases additional framing is required to support the lining because the steel girts spacing exceeds the spacing capacity of most linings. The lining support in these cases is assumed to be either 75 x 50 mm (for spans less than 1.4 m) or 100 x 50 mm timber framing, for spans over 1.4 m, installed over or between the girts.

Coated fibre-cement sheet, and uncoated plywood sheet, both with timber framing, are significantly more expensive than pre-painted steel cladding but as the timber framing doubles as the lining support the differentials are partly offset. The concrete claddings are self-supporting but require timber strapping to support the lining and there are extra foundation costs due to the high dead load of the concrete wall, which are included in Table 12.

Tables 13, 14, and 15 show the detailed results for 0.40 mm and 0.55 mm steel profiles supported by cold-formed galvanised steel purlins and girts. The structural designs are of four typical low-rise industrial/commercial buildings in Auckland. The designs are for intermediate spans only (i.e. for simplicity the building edges, which have higher wind loads, are not included in the analysis). The Dimond Industries design manuals were used, [(9)], [(10)] and the cladding types are as follows:

Hi-rib – BB900, LT&, V-rib.
Low-rib – Spandex, Trimdek, Windex, Styleline.
Trough – Dimondek 300 and Dimondek 400.
Near flat sheet – Fineline.

It is noticeable that the minimum initial cost solution for steel cladding and cladding support costs are fairly similar over the range of building sizes, stud heights and portal spacings. The range for 0.40 mm sheet walls is $53/sq metre to $57/sq metre, (ignoring the trough sections), and for 0.40 mm sheet roofs the range is $53/sq metre to $55/sq metre. Also the 0.40 mm sheet solutions are cheaper than the 0.55 mm sheet designs in all cases by between $1 to $4/sq metre.

Similar calculations were done for aluminium profiles. These are available from the author. Again the lighter sheet has a lower cost than the heavier sheet.

Calculations were also done for higher wind loads in which the wind loading on the steel profiles was increased from approximately 1.0 kPa in the earlier Tables to 2.0 kPa, and these results are also available from the author. The minimum initial cost solution varies between building sizes, from $59/sq metre to $63/sq metre for 0.40 mm sheet walls and from $57/sq metre to $63/sq metre for 0.40 mm sheet roofs. Again the 0.40 mm sheet and supports was cheaper than the 0.55 mm sheet and supports.

Table 12. Cladding systems initial costs.

Commercial/industrial buildings claddings initial costs

	SUPPORT STRUCTURE	Cladding $/sqm	INITIAL COSTS $/Sq metre Cladding support	Sub total	Lining support	Total	INITIAL COSTS $/Sq metre Cladding support	Sub total	Lining support	Total
WALL CLADDING			**Medium building**				**Large building**			
Steel 0.40 mm, zinc/alum, polyester pre-paint										
Corrugated	Steel girts	30	23	53	23	76	28	58	23	81
Low-rib	Steel girts	32	21	53	26	79	26	58	26	84
High-rib	Steel girts	35	21	56	26	82	22	57	26	83
Trough	Steel girts	51	22	73	26	99	26	77	26	103
Steel 0.55 mm, zinc/alum, polyester pre-paint										
Near flat	Steel girts	30	40	70	0	70	44	74	0	74
Corrugated	Steel girts	32	22	54	23	77	26	58	23	81
Low-rib	Steel girts	34	21	55	26	81	23	57	26	83
High-rib	Steel girts	39	19	58	26	84	20	59	26	85
Trough	Steel girts	54	21	75	26	101	26	80	26	106
Aluminium 0.70 mm, no coat										
High-rib	Steel girts	45	22	67	26	93	26	71	26	97
Trough	Steel girts	69	24	93	26	119	30	99	26	125
Aluminium 0.90 mm, no coat										
High-rib	Steel girts	48	21	69	26	95	23	71	26	97
Trough	Steel girts	82	22	104	26	130	26	108	26	134
Fibre-cement flat sheet, painted										
6 mm PVC jointers	200x50 frame@600	40	40	80	0	80				
7.5 mm Textured	200x50 frame@600	71	40	111	0	111				
Fibre-cement corrugated sheet, no coat										
	Steel girts	78	23	101	23	124				
Plywood sheet, 12 mm, H3 treated										
Plain surface, no paint coat		39	40	79	0	79				
Textured surface, no paint coat		48	40	88	0	88				
Concrete tilt slab										
125 mm thick	self support	90	10	100	10	110				
150 mm thick	self support	105					12	117	10	127
Concrete block, reinforced, grouted										
150 mm	self support	80	15	95	10	105				
200 mm	self support	100					12	112	10	122
ROOF CLADDING										
Steel 0.40 mm, zinc/alum, polyester pre-paint										
Corrugated	Steel purlins	30	26	56			29	59		
Low-rib	Steel purlins	32	24	56			28	60		
High-rib	Steel purlins	35	20	55			19	54		
Trough	Steel purlins	51	24	75			31	82		
Steel 0.55 mm, zinc/alum, polyester pre-paint										
Corrugated	Steel purlins	32	24	56			26	58		
Low-rib	Steel purlins	34	24	58			24	58		
High-rib	Steel purlins	39	18	57			19	58		
Trough	Steel purlins	54	24	78			26	80		
Aluminium 0.70 mm, no coat										
High-rib	Steel purlins	45	23	68			30	75		
Trough	Steel purlins	69	31	100			39	108		
Aluminium 0.90 mm, no coat										
High-rib	Steel purlins	48	21	69			23	71		
Trough	Steel purlins	82	23	105			28	110		
Fibre-cement corrugated sheet, no coat										
	Steel purlins	78	26	104			29	107		

All options are to the same wind design load, for typical light commercial/ industrial single-storey buildings in Auckland.
The main structure is a steel portal:
Medium building - Portals @ 6 m spacings, 20 m span, 6 m stud height.
Large building - Portal @10 m spacings, 40 m span, 9 m stud height.
The wall lining support for steel walls is 75 x 50 mm framing for girt spacing less than 1.2 m, otherwise 100 x 50 mm framing timber.
The wall lining for concrete walls is 50 x 50 mm timber strapping.

Table 13. Steel cladding 0.40 mm and purlin/girt costs.

Steel cladding 0.40 mm, and purlin/girt costs

0.40 mm sheet

Small building
Portal span = 16 m
Portal spacings= 4 m ctrs
Stud ht= 4 m
Roof chord lgth= 8.2 m

Small building

	Allowable span Intermediate span Wall (m)	Roof (m)	Cost $/sqm	Walls: Girts Numb	Spacing m	Girt ld ult kN/m	Girt ld service kN/m	Girt type	Braces /span	Cost $/sqm	Roof: Purlins Numb	Spacing m	Purl ld ult kN/m	Purl ld service kN/m	Purlin type	Braces /span	Cost $/sqm
Steelspan900	4.0	3.7	37	2	4.0	2.06	1.34	1	1	53.0	4	3.2	3.4	2.2	2	1	53.2
BB900	2.5	2.1	35	3	2.0	2.06	1.34	1	1	57.0	6	1.8	1.9	1.2	1	1	56.6
LT7	2.6	1.7	35	3	2.0	2.06	1.34	1	1	57.0	7	1.5	1.6	1.0	1	1	59.5
V-RIB	2.6	1.65	35	3	2.0	2.06	1.34	1	1	57.0	7	1.5	1.6	1.0	1	1	59.5
Trimdek	2.0	1.6	32	3	2.0	2.06	1.34	1	1	54.0	7	1.5	1.6	1.0	1	1	56.5
Windex	2.0	1.5	32	3	2.0	2.06	1.34	1	1	54.0	7	1.5	1.6	1.0	1	1	56.5
Styleline	2.0	1.5	32	3	2.0	2.06	1.34	1	1	54.0	7	1.5	1.6	1.0	1	1	56.5
Corrugated	1.45	1.2	30	4	1.3	1.37	0.89	1	1	58.0	9	1.1	1.2	0.8	1	1	60.3
Fineline	na	na	na	na	na	na	na			na	na	na	na				
Dimondek300	2.25	1.6	55	3	2.0	2.06	1.34	1	1	77.0	7	1.5	1.6	1.0	1	1	79.5
Dimondek400	1.85	1.25	51	4	1.3	1.37	0.89	1	1	79.0	8	1.2	1.3	0.9	1	1	78.4

Medium building
Portal span = 20 m
Portal spacings= 6 m ctrs
Stud ht= 6 m
Roof chord lgth= 10.4 m

Medium building

	Walls: Girts Numb	Spacing m	Girt ld ult kN/m	Girt ld service kN/m	Girt type	Braces /span	Cost $/sqm	Roof: Purlins Numb	Spacing m	Purl ld ult kN/m	Purl ld service kN/m	Purlin type	Braces /span	Cost $/sqm
Steelspan900	3	3.0	3.09	2.01	7	1	55.5	5	2.9	3.12	2.0	7	1	54.9
BB900	4	2.0	2.06	1.34	4	1	56.1	7	1.9	2.01	1.3	4	1	56.3
LT7	4	2.0	2.06	1.34	4	1	56.1	8	1.6	1.70	1.1	4	1	58.9
V-RIB	4	2.0	2.06	1.34	4	1	56.1	8	1.6	1.70	1.1	4	1	58.9
Trimdek	4	2.0	2.06	1.34	4	1	53.1	8	1.6	1.70	1.1	4	1	55.9
Windex	4	2.0	2.06	1.34	4	1	53.1	9	1.4	1.48	1.0	3	1	55.1
Styleline	4	2.0	2.06	1.34	4	1	53.1	9	1.4	1.48	1.0	3	1	55.1
Corrugated	6	1.2	1.236	0.804	2	1	54.3	11	1.1	1.17	0.8	2	1	55.6
Fineline	na	na	na	na			na	na	na	na				
Dimondek300	4	2.0	2.06	1.34	4	1	76.1	8	1.6	1.70	1.1	4	1	78.9
Dimondek400	5	1.5	1.545	1.005	3	1	73.4	10	1.2	1.31	0.8	2	1	74.5

Table 13 (continued)

0.40 mm

Moderate building
Portal span = 30 m
Portal spacings= 8 m ctrs
Stud ht= 8 m
Roof chord lgth= 15.5 m

Moderate building

	Walls: Girts Numb	Spacing m	Girt ld ult kN/m	Girt ld service kN/m	Girt type	Braces /span	Cost $/sqm	Roof: Purlins Numb	Spacing m	Purl ld ult kN/m	Purl ld service kN/m	Purlin type	Braces /span	Cost $/sqm
Steelspan900	3	4.0	4.12	2.68	11	2	54.9	6	3.4	3.64	2.4	11	1	53.3
BB900	5	2.0	2.06	1.34	8	2	58.4	9	2.0	2.20	1.4	9	1	56.2
LT7	5	2.0	2.06	1.34	8	2	58.4	11	1.6	1.74	1.1	8	1	59.0
V-RIB	5	2.0	2.06	1.34	8	2	58.4	11	1.6	1.74	1.1	8	1	59.0
Trimdek	5	2.0	2.06	1.34	8	2	55.4	12	1.5	1.58	1.0	7	1	57.2
Windex	5	2.0	2.06	1.34	8	2	55.4	12	1.5	1.58	1.0	7	1	57.2
Styleline	5	2.0	2.06	1.34	8	2	55.4	12	1.5	1.58	1.0	7	1	57.2
Corrugated	7	1.3	1.37	0.89	5	2	57.6	15	1.1	1.23	0.8	6	1	59.1
Fineline	na	na	na	na			na	na	na	na				
Dimondek300	5	2.0	2.06	1.34	8	2	78.4	12	1.5	1.58	1.0	7	1	80.2
Dimondek400	6	1.6	1.65	1.07	5	2	75.3	14	1.2	1.33	0.9	7	1	80.1

Large building
Portal span = 40 m
Portal spacings= 10 m ctrs
Stud ht= 9 m
Roof chord lgth= 20.71 m

Large building

	Walls: Girts Numb	Spacing m	Girt ld ult kN/m	Girt ld service kN/m	Girt type	Braces /span	Cost $/sqm	Roof: Purlins Numb	Spacing m	Purl ld ult kN/m	Purl ld service kN/m	Purlin type	Braces /span	Cost $/sqm
Steelspan900	4	3.0	3.09	2.01	12	2	56.6	7	3.7	3.99	2.6	12	3	54.3
BB900	5	2.3	2.32	1.51	11	2	58.2	12	2.0	2.11	1.4	12	1	58.0
LT7	5	2.3	2.32	1.51	11	2	58.2	14	1.6	1.78	1.2	11	1	60.9
V-RIB	5	2.3	2.32	1.51	11	2	58.2	14	1.6	1.78	1.2	11	1	60.9
Trimdek	6	1.8	1.85	1.21	10	2	57.9	15	1.5	1.64	1.1	11	1	59.7
Windex	6	1.8	1.85	1.21	10	2	57.9	16	1.4	1.53	1.0	10	1	59.9
Styleline	6	1.8	1.85	1.21	10	2	57.9	16	1.4	1.53	1.0	10	1	59.9
Corrugated	8	1.3	1.32	0.86	8	2	59.9	19	1.2	1.27	0.8	8	1	59.1
Fineline	na	na	na	na				na	na	na				
Dimondek300	5	2.3	2.32	1.51	11	2	78.2	15	1.5	1.64	1.1	11	1	82.7
Dimondek400	6	1.8	1.85	1.21	10	2	76.9	18	1.2	1.35	0.9	10	1	82.2

Notes: See Table 14 for purlin/ girt type, costs and design parameters.
Design is for a typical site in Auckland.
Cladding and girt/ purlin spans are from the Dimond design manuals.
Bracing for wall girts is at a maximum spacing of 3m centres as per the Dimond recommendation.

Table 14. Steel cladding 0.55 mm and purlin/girt costs.

Steel cladding 0.55 mm, and purlin/girt costs

0.55 mm sheet

Cladding	Allowable span Intermediate span Wall (m)	Roof (m)	Cost $/sqm
Steelspan900	4.0	3.7	41
BB900	3.3	2.9	39
LT7	3.7	2.7	39
V-RIB	3.05	2.2	39
Trimdek	2.4	1.8	34
Windek	2.4	1.7	34
Styleline	2.4	1.7	34
Corrugated	1.85	1.6	32
Fineline	0.73	na	30
Dimondek300	2.6	2.0	63
Dimondek400	2.2	1.6	54

Small building

Portal span = 16 m
Portal spacings= 4 m ctrs
Stud ht= 4 m
Roof chord lgth= 8.2 m

Small building

Cladding	Walls: Girts Numb	Spacing m	Girt ld ult kN/m	Girt ld service kN/m	Girt type	Braces /span	Cost $/sqm	Roof: Purlins Numb	Spacing m	Purl ld ult kN/m	Purl ld service kN/m	Purlin type	Braces /span	Cost $/sqm
Steelspan900	2	4.0	2.06	1.34	1	1	57.0	4	3.2	3.4	2.2	2	1	57.2
BB900	3	2.0	2.06	1.34	1	1	61.0	5	2.3	2.5	1.6	1	1	57.6
LT7	3	2.0	2.06	1.34	1	1	61.0	5	2.3	2.5	1.6	1	1	57.6
V-RIB	3	2.0	2.06	1.34	1	1	61.0	6	1.8	1.9	1.2	1	1	60.6
Trimdek	3	2.0	2.06	1.34	1	1	56.0	6	1.8	1.9	1.2	1	1	55.6
Windek	3	2.0	2.06	1.34	1	1	56.0	7	1.5	1.6	1.0	1	1	58.5
Styleline	3	2.0	2.06	1.34	1	1	56.0	7	1.5	1.6	1.0	1	1	58.5
Corrugated	4	1.3	1.37	0.89	1	1	60.0	7	1.5	1.6	1.0	1	1	56.5
Fineline	7	0.7	0.69	0.45	1	1	76.0	na	na	na				
Dimondek300	3	2.0	2.06	1.34	1	1	85.0	6	1.8	1.9	1.2	1	1	84.6
Dimondek400	3	2.0	2.06	1.34	1	1	76.0	7	1.5	1.6	1.0	1	1	78.5

Medium building

Portal span = 20 m
Portal spacings= 6 m ctrs
Stud ht= 6 m
Roof chord lgth= 10.4 m

Medium building

Cladding	Walls: Girts Numb	Spacing m	Girt ld ult kN/m	Girt ld service kN/m	Girt type	Braces /span	Cost $/sqm	Roof: Purlins Numb	Spacing m	Purl ld ult kN/m	Purl ld service kN/m	Purlin type	Braces /span	Cost $/sqm
Steelspan900	3	3.0	3.09	2.01	7	1	59.5	5	2.9	3.1	2.0	7	1	58.9
BB900	3	3.0	3.09	2.01	7	1	57.5	5	2.9	3.1	2.0	7	1	56.9
LT7	3	3.0	3.09	2.01	7	1	57.5	6	2.3	2.4	1.6	5	1	58.2
V-RIB	3	3.0	3.09	2.01	7	1	57.5	7	1.9	2.0	1.3	4	1	60.3
Trimdek	4	2.0	2.06	1.34	4	1	55.1	8	1.6	1.7	1.1	4	1	57.9
Windek	4	2.0	2.06	1.34	4	1	55.1	8	1.6	1.7	1.1	4	1	57.9
Styleline	4	2.0	2.06	1.34	4	1	55.1	8	1.6	1.7	1.1	4	1	57.9
Corrugated	5	1.5	1.55	1.01	3	1	54.4	8	1.6	1.7	1.1	4	1	55.9
Fineline	10	0.7	0.69	0.45	1	1	67.1	na	na	na				
Dimondek300	4	2.0	2.06	1.34	4	1	84.1	7	1.9	2.0	1.3	4	1	84.3
Dimondek400	4	2.0	2.06	1.34	4	1	75.1	8	1.6	1.7	1.1	4	1	77.9

Table 14 (continued)

0.55 mm

Moderate building

Portal span = 30 m
Portal spacings= 8 m ctrs
Stud ht= 8 m
Roof chord lgth= 15.5 m

Moderate building

Cladding	Walls: Girts Numb	Spacing m	Girt ld ult kN/m	Girt ld service kN/m	Girt type	Braces /span	Cost $/sqm	Roof: Purlins Numb	Spacing m	Purl ld ult kN/m	Purl ld service kN/m	Purlin type	Braces /span	Cost $/sqm
Steelspan900	3	4.0	4.12	2.68	11	2	58.9	6	3.4	3.64	2.36	11	1	57.3
BB900	4	2.7	2.75	1.79	9	2	59.5	7	2.8	2.99	1.94	10	1	56.8
LT7	4	2.7	2.75	1.79	9	2	59.5	8	2.3	2.54	1.64	10	1	59.1
V-RIB	4	2.7	2.75	1.79	9	2	59.5	9	2.0	2.20	1.43	9	1	60.2
TRIMDEK	5	2.0	2.06	1.34	7	2	56.8	11	1.6	1.74	1.13	8	1	58.0
WINDEK	5	2.0	2.06	1.34	7	2	56.8	11	1.6	1.74	1.13	8	1	58.0
STYLELINE	5	2.0	2.06	1.34	7	2	56.8	11	1.6	1.74	1.13	8	1	58.0
CORRUGATED	6	1.6	1.65	1.07	6	2	57.0	12	1.5	1.58	1.02	7	1	57.2
FINELINE	12	0.7	0.75	0.49	2	2	64.0	na	na	na				
Dimondek300	5	2.0	2.06	1.34	7	2	85.8	10	1.8	1.95	1.26	8	1	85.0
Dimondek400	5	2.0	2.06	1.34	7	2	76.8	12	1.5	1.58	1.02	7	1	79.2

Large building

Portal span = 40 m
Portal spacings= 10 m ctrs
Stud ht= 9 m
Roof chord lgth= 20.71 m

Large building

Cladding	Walls: Girts Numb	Spacing m	Girt ld ult kN/m	Girt ld service kN/m	Girt type	Braces /span	Cost $/sqm	Roof: Purlins Numb	Spacing m	Purl ld ult kN/m	Purl ld service kN/m	Purlin type	Braces /span	Cost $/sqm
Steelspan900	4	3.0	3.09	2.01	12	2	60.6	7	3.7	3.99	2.59	12	3	58.3
BB900	4	3.0	3.09	2.01	12	2	58.6	9	2.7	2.94	1.91	12	2	58.3
LT7	4	3.0	3.09	2.01	12	2	58.6	10	2.4	2.60	1.69	12	1	58.5
V-RIB	4	3.0	3.09	2.01	12	2	58.6	11	2.2	2.33	1.51	12	1	60.3
TRIMDEK	5	2.3	2.32	1.51	11	2	57.2	13	1.8	1.93	1.25	11	1	58.2
WINDEK	5	2.3	2.32	1.51	11	2	57.2	14	1.6	1.78	1.15	11	1	59.9
STYLELINE	5	2.3	2.32	1.51	11	2	57.2	14	1.6	1.78	1.15	11	1	59.9
CORRUGATED	6	1.8	1.85	1.21	10	2	57.9	15	1.5	1.64	1.07	9	2	58.4
FINELINE	14	0.7	0.71	0.46	5	2	73.6	na	na	na				
Dimondek300	5	2.3	2.32	1.51	11	2	86.2	12	2.0	2.11	1.37	10	2	85.9
Dimondek400	6	1.8	1.85	1.21	10	2	79.9	15	1.5	1.64	1.07	9	2	80.4

Table 15. Design and cost parameters for cladding systems.

Design and cost parameters for cladding/ support systems												
GIRTS/ PURLINS	150/12	150/15	200/12	200/15	200/18	250/13	250/15	250/18	300/15	300/18	350/18	400/20
Type	1	2	3	4	5	6	7	8	9	10	11	12
$/m	14	15	17	21	22	23	25	26	28	30	32	33
Bracing cost $/m/brace =			16	$ channel or tie rod				Cleats + bolts/span=			40	$ ea
Steel cladding system costs include cladding + girts/purlins+ bracing channels/tie rods girt/purlin cleats & bolts.												
Fibre-cement and plywood sheet cladding												
Small (4m stud) & Medium Bldg (6m stud) only					200x50 @ 600 ctrs + dwangs @ 1.2m, top girt DHS200/15							
Wind load design												
Intermediate wall		1.03 kPa	ult		Note:							
		0.67	service ld		1 kN point load, rather than wind load, governs for							
Intermediate roof		1.08 kPa	ult		most profiles for roof cladding.							
		0.70	service ld									
kg/m	3.01	3.78	3.73	4.69	5.64	4.89	5.66	6.81	6.7	8.06	8.89	10.81

APPENDIX 3: TREATMENT OF NON-QUANTIFIABLE FACTORS

This appendix discusses two procedures for incorporating intangible or hard to quantify variables in the decision-making process. They use similar methodology, and the first procedure is suitable for use on complex decision problems, using computer software. The second procedure can be carried out manually on simple problems with up to approximately eight decision variables. They are:

- the analytical hierarchical process (AHP), and
- weighted evaluation method.

A3.1 Analytical hierarchical process

In this process the attributes or choice factors are compared with each other either by a ranking system, or by a series of pairwise comparisons which enables the weights of each factor to be derived. Then the various materials are rated under each factor, either by a ranking system, or again by a pairwise comparison process. Where quantifiable measures are available, (e.g. the annual life cycle cost, or the fire rating of the material in minutes) these are used to rank the materials directly rather than carrying out pairwise comparisons. The weights of each choice factor are then applied and an overall 'score' is derived for each material and the highest scoring material is revealed as the preferred option.

Two examples using LCC of claddings and other choice factors are shown in Figures 8 and 9. The examples are those given as Trial 1 and Trial 3 in Table 9. The choice factors are:

- LCC of claddings as given in Table 2.
- Impact resistance of the claddings with two sub-attributes under this heading, namely accidental damage resistance, and resistance to forced entry through the cladding.
- Aesthetics of the cladding with two sub-attributes under this heading, namely texture and colour choice.
- Fire resistance of the claddings and support system.
- Environmental impact of the cladding and support materials in terms of CO_2 emissions.

The Figures 8 and 9 show the output from a software package called Expert Choice Pro[11], which facilitates the AHP as described above. For Trial 1 the choice factor weights as revealed by the ranking is life cycle costs 39%, aesthetics 7%, impact resistance 31% and fire resistance 23%, summing to 100%. This is an owner with costs and security and wearing attributes as the most important decision factors. In this case the analysis reveals the tilt slab option is the preferred option. Tilt slab and concrete block rated high on the impact- and fire-resistant factors which outweighed the low scores for costs and aesthetics.

In Trial 3 CO_2 emissions have been added as another decision factor and the decision maker has rated this equally with costs; the other decision factors being relatively unimportant. The weights are LCC 32%, aesthetics 18%, impact resistance 6%, fire resistance 12% and environmental impacts 32%. In this case the analysis reveals that plywood sheet and fibre-cement sheet are the preferred options. At present this heavy weighting for the environmental effects is unlikely to be selected by most clients. However, CO_2 emissions friendly buildings are being constructed now which look at the whole building and its operation, rather than just the cladding. Trade-offs are involved between cost and the whole range of "green" subjective issues, and the AHP method can be used to facilitate these trade-offs.

Obviously the outcome depends to a large extent on individual preferences, especially concerning the aesthetic rating of materials, and the relative weights given to the decision factors. Details of these preferences used in the trials are in Table 16. Note that the aesthetics has two sub-categories: colour and texture, which are weighted equally. The impact category also has two sub-categories: accidental damage resistance, and resistance to forced entry, again weighted equally.

The AHP is a tool that is used widely in business to help make decisions involving intangible or non-quantifiable factors in a structured manner. For example it has been used for selection on a new building for a business. This case is illustrated in an ASTM paper "Applying analytical hierarchy process to multi-attribute decision analysis of investments related to buildings and building systems." (5). Figure 10 is from this paper and indicates that various layers of attributes can be applied to the decision process. For example under accessibility the sub-sets are accessibility of the building to staff, i.e. how close to work are staff on average, accessibility to clients, i.e. where is the site in relation to the main clients. A third factor could be public transport accessibility, which may differ from the other two factors.

At each level of the hierarchy the decision makers have to decide what weight to apply to each attribute at that level. For example how much weight to apply to each of staff and clients under the accessibility attribute, or how much weight should be applied to each of aesthetics, accessibility, availability, annual costs and environment, at the first level. This can be done in a pairwise fashion, or by ranking.

The shaded "leaf" attributes then have all building alternatives assessed (pairwise comparisons, or ranked) on how they score on that attribute. When using pairwise comparisons the software allows for quantitative estimates of how much more important one factor is compared to the other. When all comparisons are complete at any level of the hierarchy the programme checks for consistency of comparisons, (i.e. if A is preferred to B, and B is preferred to C, then the programme checks that A is preferable to C). The end result is the final desirability score for each alternative building and the highest scoring alternative is revealed as the favoured option. The software readily carries out sensitivity analysis so that the importance of various factors can be assessed.

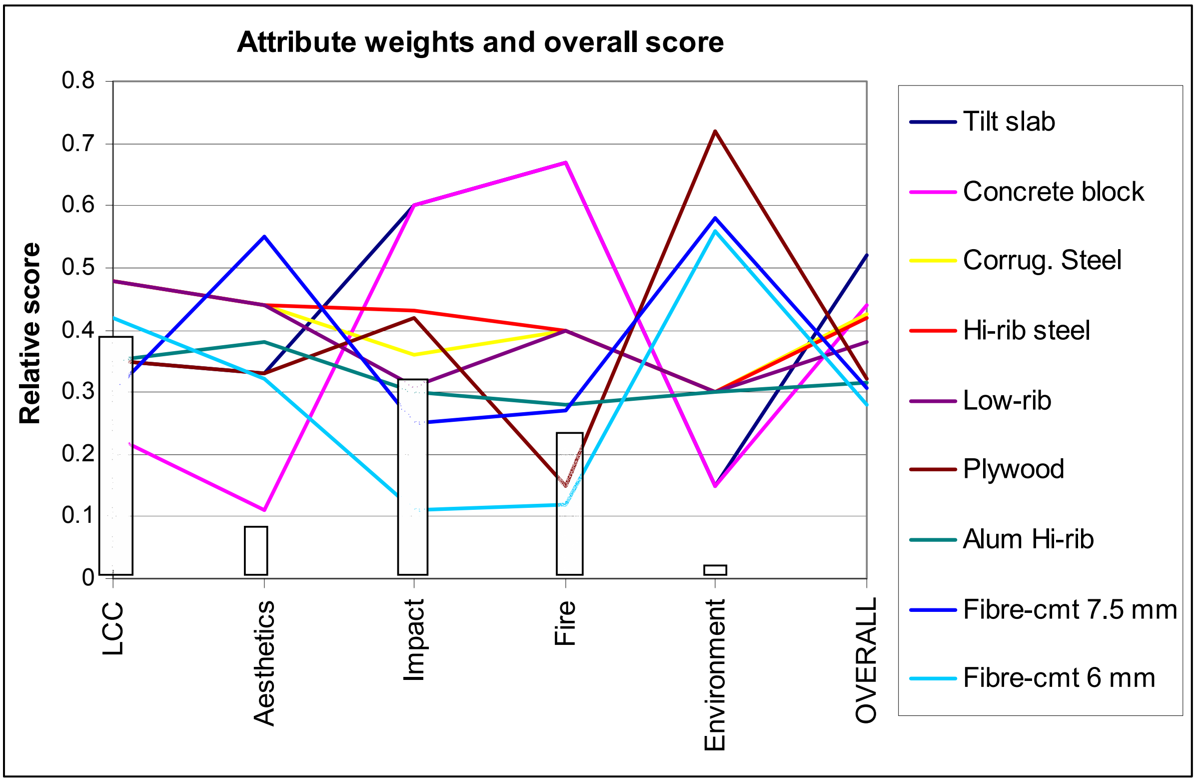


Figure 8. AHP trial 1 output

This output shows the "scores" of claddings when costs, aesthetics, impact resistance, fire resistance and CO_2 emissions for each cladding type, are combined in a decision model. The final scores are ranked in order of merit, top to bottom, on the right vertical axis. The bars on the horizontal axis indicate the amount of weight given to each decision criteria. The lines show how each material scores for each decision criteria. In "Trial 1" a heavy weighting is given to costs and impact resistance, and less or zero weighting to the other factors (see Table 16). Tilt slab is revealed as the preferred option.

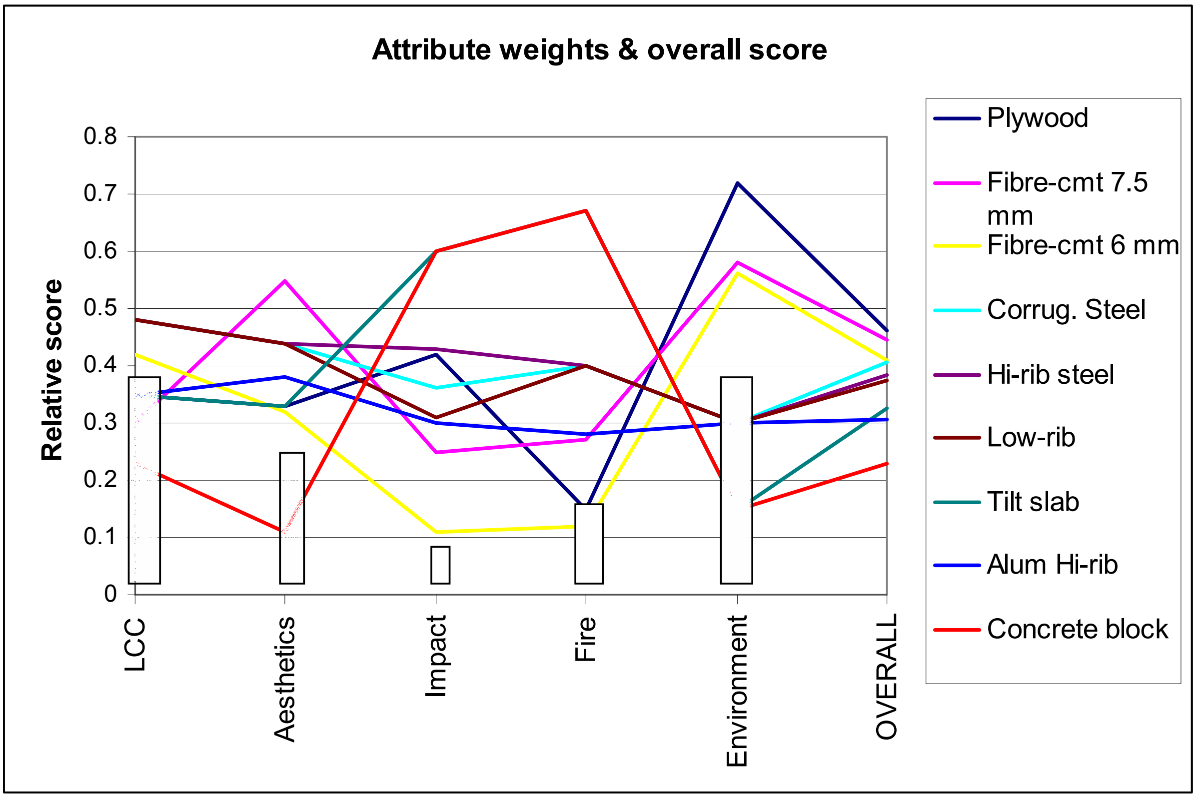
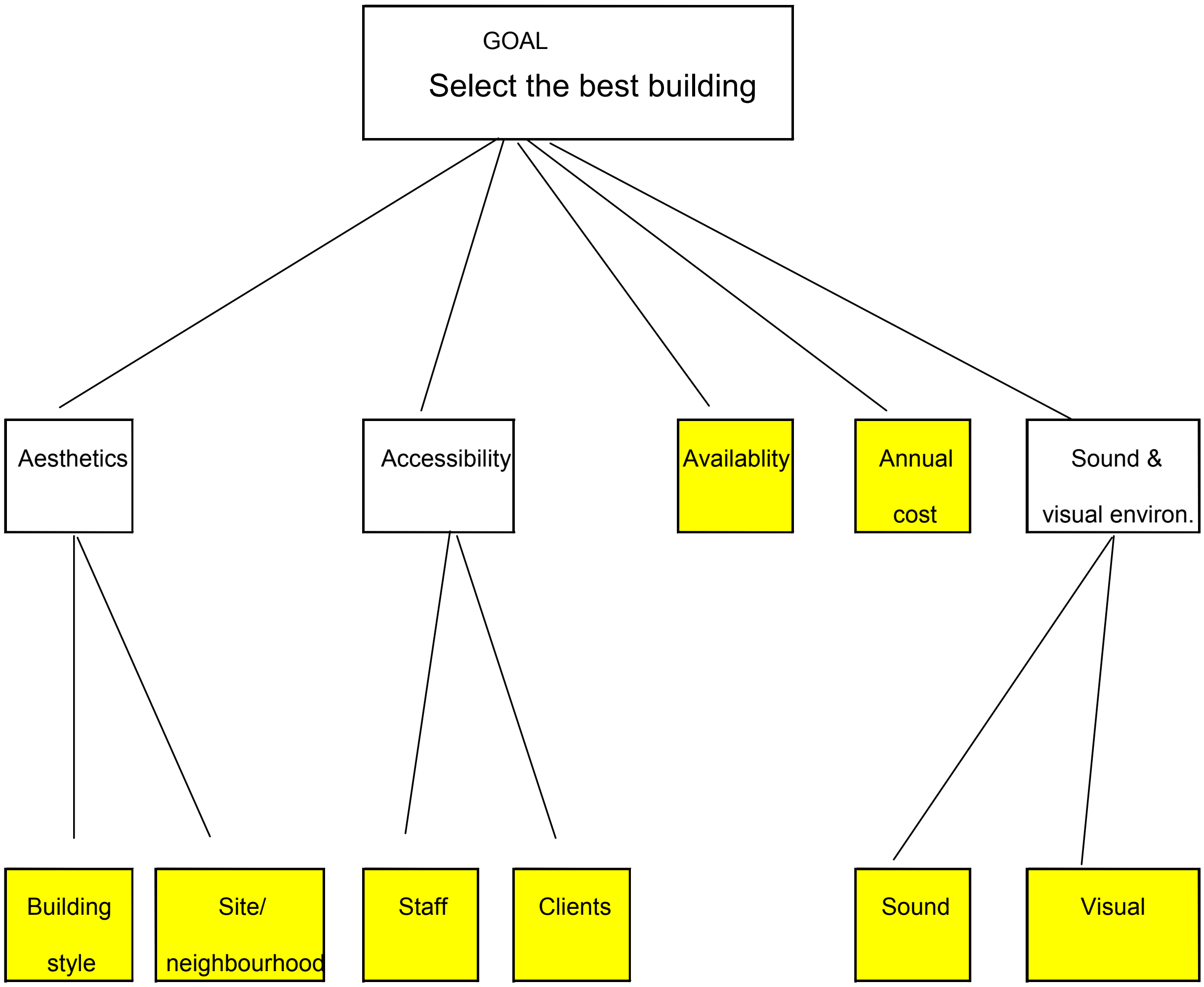


Figure 9. AHP trial 3 output

This output shows the 'scores' of claddings when costs, aesthetics, impact resistance, fire resistance and CO_2 emissions (environmental impacts) for each cladding type are combined in a decision model. The final scores are ranked in order of merit, top to bottom, on the right vertical axis. The bars on the horizontal axis indicate the amount of weight given to each decision criteria. The lines show how each material scores for each decision criteria. In "Trial 3" a heavy weighting is given to costs and environmental impacts, and less weighting to the other factors (see Table 16). Plywood sheet is revealed as the preferred option.

Figure 10. AHP for a building selection problem



"Leaf" attributes are shaded. These are the decision factors that are scored for each building.

Note: This diagram is taken from an ASTM paper "Applying analytical hierarchy process to multi-attribute decision analysis of investments related to buildings and building systems." (5).

Table 16. AHP cladding systems material scores and weights.

AHP cladding material scores and weights

---Cladding scores -----------------------------

Decision factor =	LCC	Aesthetics		Fire resistance	Impact resistance		Environmental
Decision sub-factor =		Texture	Colour		Accidential	Deliberate	
Steel 0.40 mm, polyester pre-painted							
Corrugated	4	3	5	3	2	4	2
Low-rib	3.5	3	5	3	1	4	2
Hi-rib	3	3	5	3	3	4	2
Trough	3	1	5	3	3	4	2
Alum 0.70 mm hi-rib	3.5	4	3	2	2	3	1
Fibre-cement sheet, painted							
6 mm, PVC jointers	4	2	4	1	1	1	4
7.5 mm, stopped/ textured	2	5	5	2	2	2	4
Plywood sheet 12 mm							
Plain	3.5	2	1	1	4	3	5
Textured	3	4	2	1	4	3	5
Concrete							
125 mm tilt slab	2.5	3	3	5	5	5	1
200 mm block	2	1	1	5	5	5	1

CODE	Material score		or	Weight
	5	Excellent	or	Very important
	4	Good		Important
	3	Average		Sometimes important
	2	Poor		Minor consideration
	1	Very poor		Not important at all

Weight applied to the following factors:

	LCC	Aesthetics	Fire resistance	Impact resistance	Environmental
Trial 1	5	1	3	4	na
Trial 2	3	5	1	2	na
Trial 3	5	3	2	1	5

A3.2 Weighted evaluation method

This method for combining LCC with other decision variables can be performed manually; it assumes only one layer of decision variables, and fewer than about eight decision variables. In the example below the aim is to choose the best cladding system, and the variables given are LCC, aesthetics, impact resistance, and fire resistance. The same material scoring as in Trial 1, Table 16 are used, and the method is shown below in Table 17. Firstly, the weights for the decision criteria are established by comparing the criteria in pairs, so for example, in comparing aesthetics with fire resistance there is a moderate preference for fire resistance (D-3). The preference numbers for each criterion (A, B, C and D) are summed, i.e the A scores are 5, 3 and 3 =11. A has 11 preference points, B zero points, C six points and D three points. These totals are scaled so that no criterion has more than 10 points nor less than 1 point. This is an arbitrary adjustment so that no one criterion has an overwhelming influence, or a nil influence. These adjusted criteria are then used to weight the scores that each cladding achieves for each criterion. For example tilt slab scores a 5, or 'excellent' for impact resistance, and as the impact resistance criteria has a 6-point weighting, its weighted score on this criteria is 30. The unweighted scores are a simple assessment (on a scale of 5 to 1) of how each cladding performs (see Table 16). All the weighted score are added, across rows, to give the cladding total score. Tilt slab is revealed as the preferred cladding system since it has the highest total weighted score.

Table 17. Weighted evaluation example.

Mixing LCC and other criteria in the decision process

Weighting criteria	and	**Cladding score for decision**
5=Very major preference		5 = Excellent
4= Major preference		4 = Very good
3= Moderate preference		3 = Good
2= Minor preference		2 = Poor
1=No preference between		1 = Very poor

Decision criteria

		A LCC	B Aesthetics	C Impact resistance	D Fire resistance
A	LCC				
B	Aesthetics	A-5			
C	Impact resist	A-3	C-4		
D	Fire resist	A-3	D-3	C-2	
	Raw weighting	11	0	6	3
	Adjusted weighting	10	1	6	3

		A	B	C	D	Total Weighted Score
Steel corrugated.	Score	4	4	3	3	
Pre-painted	Weighted score	40	4	18	9	71
Steel Hi-rib	Score	3	4	3.5	3	
Pre-painted	Weighted score	30	4	21	9	64
Fibre-cmt textured	Score	2	5	2	2	
	Weighted score	20	5	12	6	43
Plywood, plain	Score	3.5	1.5	3.5	1	
	Weighted score	35	1.5	21	3	60.5
Tilt slab 125 mm	Score	2.5	3	5	5	
	Weighted score	25	3	30	15	73

APPENDIX 4: CALCULATIONS OF THE EFFECTS OF CARBON TAX ON MATERIAL COSTS

This appendix outlines the method of calculating the effects of a carbon charge on the life cycle costs of materials. Recent work from the Ministry of Economic Development indicates that the world price of carbon emission rights is likely to be between $10 per tonnes of CO_2 and $25 per tonnes of CO_2.

The cost effect of a carbon tax on building materials is quantified by calculating the embodied energy content in the production and installation of materials. The method is summarised in Table 18 in which wall claddings are separated into the cladding and cladding support components and their carbon emission contents are calculated separately. The net carbon emissions content of materials is based mainly on the work of Alcorn(7) but includes some data from Honey and Buchanan (6). As discussed earlier there are two off-setting factors:

- a trend to more efficient energy use by manufacturers in response to any future carbon tax.
- the carbon tax is expected to be recycled through the tax system, possibly through reduced company taxes.

Table 18 shows the calculations for the effect of a carbon tax on the initial cost of wall cladding systems. The cost increases range from 0.5% for fibre-cement systems, to 4.6% for 0.9 mm aluminium sheet. Table 19 is a reproduction of the life cycle costs shown in Table 2 but includes the carbon tax effects. The result is that life cycle costs increase by between 0.4% for sheet plywood and 3.3% for 0.90 mm aluminium. Most steel claddings have an increase of around 1.3% in life cycle costs.

The relation between carbon tax and life cycle costs for wall claddings is shown in Figure 11 for a one-sided carbon tax. There is an upward trend in the scatter of points explained by the observation that the more expensive claddings tend to have higher life cycle costs and also a higher embodied energy content (and therefore higher CO_2 release).

Table 18. Carbon tax effects on wall cladding system.

Carbon tax effects on initial cost of wall claddings and supports

Cladding	Cladding only						Cost increase	Cladding support: Girts weight	MJ/unit by fuel type					Cost increase	Cladding & supports: Cost increase	Current cost	%
		MJ/unit by fuel type: Elect	Gas	Oil	Coal	Total	$/sq m	kg/sq m	Elect	Gas	Oil	Coal	Total	$/sq m	$/sq m	$/sq m	Incr
Steel 0.40 mm, zinc/alum,	kg/sqm					(1)									(1)		
Corrugated **pre-painted**	4.42	17.5	3	3.0	11.5	35	0.5	3.78	17.5	3	3.0	11.5	35	0.5	1.0	53	1.9
Low-rib	4.45	17.5	3	3.0	11.5	35	0.5	3.13	17.5	3	3.0	11.5	35	0.4	0.9	53	1.7
High-rib	4.92	17.5	3	3.0	11.5	35	0.6	2.83	17.5	3	3.0	11.5	35	0.3	0.9	56	1.7
Trough	5.49	17.5	3	3.0	11.5	35	0.7	3.11	17.5	3	3.0	11.5	35	0.4	1.0	73	1.4
Steel 0.55 mm, zinc/alum,																	
Near flat **pre-painted**	3.93	17.5	3	3.0	11.5	35	0.5	5.02	17.5	3	3.0	11.5	35	0.6	1.1	70	1.5
Corrugated	5.88	17.5	3	3.0	11.5	35	0.7	3.11	17.5	3	3.0	11.5	35	0.4	1.1	54	2.0
Low-rib	5.97	17.5	3	3.0	11.5	35	0.7	3.13	17.5	3	3.0	11.5	35	0.4	1.1	55	2.0
High-rib	6.76	17.5	3	3.0	11.5	35	0.8	2.83	17.5	3	3.0	11.5	35	0.3	1.2	58	2.0
Trough	7.51	17.5	3	3.0	11.5	35	0.9	3.13	17.5	3	3.0	11.5	35	0.4	1.3	75	1.7
Aluminium 0.70 mm, no coat																	
High-rib	2.62	140	50	20	10	220	2.2	3.11	17.5	3	3.0	11.5	35	0.4	2.6	67	3.9
Trough	2.9	140	50	20	10	220	2.5	3.11	17.5	3	3.0	11.5	35	0.4	2.8	93	3.0
Aluminium 0.90 mm, no coat																	
High-rib	3.31	140	50	20	10	220	2.8	3.13	17.5	3	3.0	11.5	35	0.4	3.2	69	4.6
Trough	3.72	140	50	20	10	220	3.1	3.11	17.5	3	3.0	11.5	35	0.4	3.5	104	3.4
Fibre-cement Flat Sheet								Timber frame cum/sqm									
6.0 mm sheet	9.3	5.2	1.4	0.1	2.6	9.3	0.3	0.025	640	1010	860	200	2710	0.2	0.5	80	0.6
7.5 mm sheet	11.6	5.2	1.4	0.1	2.6	9.3	0.4	0.025	640	1010	860	200	2710	0.2	0.6	111	0.5
Fibre-cement Corrug. Sheet								Steel Girts									
6 mm sheet	10.5	5.2	1.4	0.1	2.6	9.3	0.4	3.78	17.5	3	3.0	11.5	35	0.5	0.8	101	0.8
Plywood sheet, H3 treated	cum/sqm							Timber frame									
12 mm sheet	0.012	1170	1300	1430	1820	5720	0.2	0.025	640	1010	860	200	2710	0.2	0.4	79	0.5
Concrete tilt slab	cum/sqm																
125 mm thick	0.125	600	300	1400	2000	4300	1.3	0.025	640	1010	860	200	2710	0.2	1.5	100	1.5
150 mm thick	0.15	600	300	1400	2000	4300	1.5	0.025	640	1010	860	200	2710	0.2	1.7	117	1.5
Concrete block, reinf, grout																	
150 mm	0.15	600	400	500	1000	2500	1.0	0.025	640	1010	860	200	2710	0.2	1.2	95	1.3
200 mm	0.2	600	400	500	1000	2500	1.4	0.025	640	1010	860	200	2710	0.2	1.5	112	1.4

Maintenance painting

	Elect	Gas	Oil	Coal	
Current fuel cost $/MJ =	0.03	0.01	0.01	0.005	(1)
$25/tonne CO_2 % Cost increase in fuel =	16	24	12	44	(2)

C tax $/sq m for maintenance painting only	
Corrugated/ low rib	0.028
High-rib/ trough	0.037
Fibre-Cmt 6 mm sheet, prime + 2 coat	0.018
Fibre-Cmt 7.5 mm sht, stopped, hi-build coat	0.073

(1) The carbon tax is assumed to be $25 per tonne CO_2.
(2) Fuel price increases due to carbon tax from Ministry of Economic Development.

Table 19. Life cycle costs of wall cladding systems with a carbon tax.

Life cycle costs of wall cladding systems with a carbon tax — DISCOUNT RATE= 8% — Depreciatr 1.08

MODERATE ENVIRONMENT — TAX FACTOR = 0.67

Wall cladding		Initial Cost $/sqm (1)	Life (Yrs)	MAINTENANCE (COSTS IN $/SQM) 1 YR	1 CST	2 YR	2 CST	3 YR	3 CST	4 YR	4 CST	5 YR	5 CST	7 YR	7 CST	Maintenance As a present value	Maintenance As an annual cost	Interest As an annual cost	Initial As an annual cost	TOTAL Annual cost
Steel 0.40 mm, zinc/ alum, unpainted																				
Corrugated	Steel girts	71.0	25													0.0	0.0	-2.6	6.7	4.07
Low-rib	Steel girts	73.9	25													0.0	0.0	-2.7	6.9	4.24
High-rib	Steel girts	74.9	25													0.0	0.0	-2.7	7.0	4.30
Trough	Steel girts	87.0	25													0.0	0.0	-3.2	8.2	4.99
Steel 0.40 mm, zinc/alum, pre-painted																				
Corrugated	Steel girts	77.0	50	15	12.02	22	11.02	29	11.02	36	14	42	11.02			8.3	0.5	-2.8	6.3	3.96
Low-rib	Steel girts	79.9	50	15	12.02	22	11.02	29	11.02	36	14	42	11.02			8.3	0.5	-2.9	6.5	4.09
High-rib	Steel girts	83.0	50	15	13.02	22	12.03	29	12.03	36	15	42	12.03			9.0	0.5	-3.0	6.8	4.26
Trough	Steel girts	100.1	50	15	14.02	22	13.03	29	13.03	36	16	42	13.03			9.7	0.5	-3.6	8.2	5.08
Steel 0.55 mm, zinc/alum, unpainted																				
Near flat	Steel girts	66.1	25													0.0	0.0	-2.4	6.2	3.79
Corrugated	Steel girts	72.1	25													0.0	0.0	-2.6	6.8	4.14
Low-rib	Steel girts	76.1	25													0.0	0.0	-2.8	7.1	4.37
High-rib	Steel girts	77.2	25													0.0	0.0	-2.8	7.2	4.43
Trough	Steel girts	86.3	25													0.0	0.0	-3.1	8.1	4.95
Steel 0.55 mm, zincalum, pre-painted																				
Near flat	Steel girts	71.1	50	15	12.02	22	11.02	29	11.02	36	14	42	11.02			8.3	0.5	-2.6	5.8	3.69
Corrugated	Steel girts	78.1	50	15	12.02	22	11.02	29	11.02	36	14	42	11.02			8.3	0.5	-2.8	6.4	4.01
Low-rib	Steel girts	82.1	50	15	12.02	22	11.02	29	11.02	36	14	42	11.02			8.3	0.5	-3.0	6.7	4.19
High-rib	Steel girts	85.2	50	15	13.02	22	12.03	29	12.03	36	15	42	12.03			9.0	0.5	-3.1	7.0	4.37
Trough	Steel girts	102.3	50	15	14.02	22	13.03	29	13.03	36	16	42	13.03			9.7	0.5	-3.7	8.4	5.18
Aluminium 0.70 mm, no coat																				
High-rib	Steel girts	95.6	70													0.0	0.0	-3.5	7.7	4.21
Trough	Steel girts	121.8	70													0.0	0.0	-4.4	9.8	5.37
Aluminium 0.90 mm, no coat																				
High-rib	Steel girts	98.2	80													0.0	0.0	-3.6	7.9	4.31
Trough	Steel girts	133.5	80													0.0	0.0	-4.8	10.7	5.86
Fibre-cement flat sheet, coated																				
6 mm PVC joints	Timber frame	80.5	50	10	5.02	20	5.02	30	5.02	40	5.02					4.1	0.2	-2.9	6.6	3.89
7.5 mm Stopped	Timber frame	111.7	60	10	5.02	20	5.02	30	5.02	40	5.02	50	5.02			4.2	0.2	-4.1	9.0	5.20
Fibre-cement corrugated sheet, no coat																				
6 mm corrugated	Steel girts	124.8	40													0.0	0.0	-4.5	10.5	5.94
Plywood sheet, 12 mm, H3 treated, no coat																				
Plain surface	Timber frame	79.4	30													0.0	0.0	-2.9	7.0	4.17
Texture surface	Timber frame	88.4	30													0.0	0.0	-3.2	7.8	4.64
Concrete tilt slab, no coat																				
125 mm thick	self supporting	111.5	80	20	5.02	40	5.02	60	5.02							1.4	0.1	-4.0	8.9	4.96
150 mm thick	self supporting	128.7	80	20	5.02	40	5.02	60	5.02							1.4	0.1	-4.7	10.3	5.72
Concrete block, no coat																				
150 mm	self supporting	106.2	80	30	10.03	60	10									1.1	0.1	-3.9	8.5	4.72
200 mm	self supporting	123.5	80	30	10.03	60	10									1.1	0.1	-4.5	9.9	5.48

(1) Initial costs include the cladding support and initial paint coat on the non-pre-painted steel claddings, and the initial coatings on the fibre-cement flat sheet.
Carbon tax is $25/tonne.

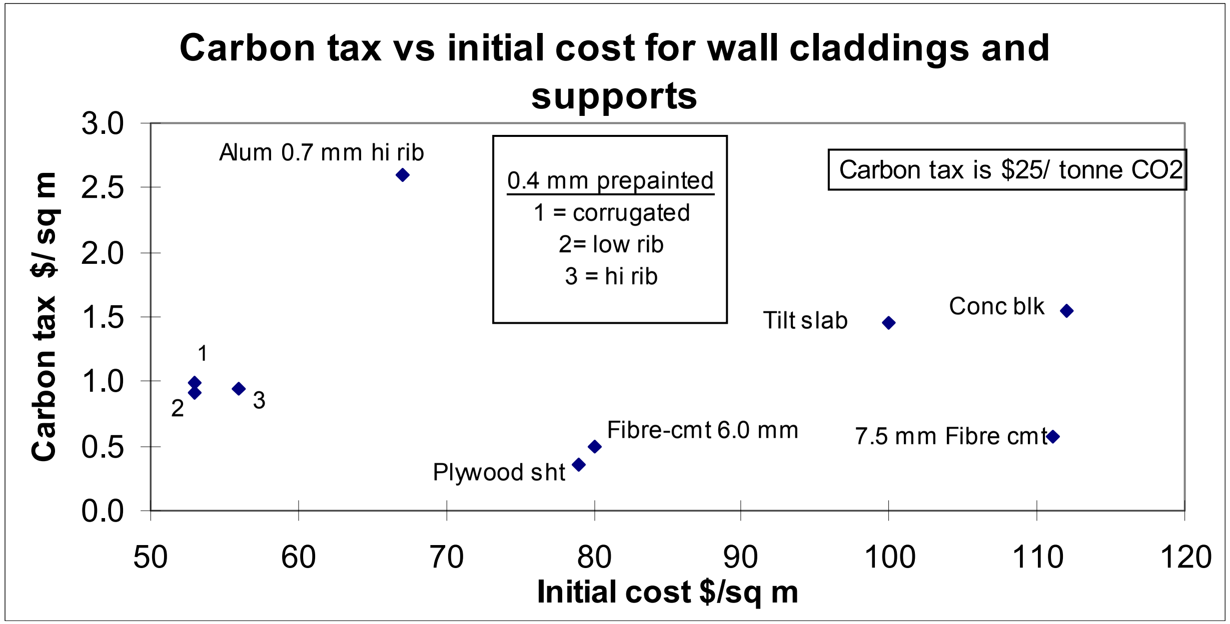


Figure 11. Carbon tax versus LCC