STUDY REPORT

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Life cycle costs and analysis of roof cladding systems

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Preface

This report is on the life cycle cost (LCC) and ranking of common roof claddings used on New Zealand dwellings. Costs and rankings data is based on an Excel calculator tool created by BRANZ for common roof cladding systems used in New Zealand dwellings. The tool combines costs with sustainability impact factors (CO_2, embodied energy and recyclability), to which the user applies weights to give a total cost-sustainability score and the ability to rank selected claddings.

Acknowledgments

This work was funded by the Building Research Levy.

Note

This report is intended for designers, builders, developers and officials.

Life cycle costs and analysis of roof cladding systems

BRANZ Study Report SR 248

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Abstract

Costs of materials are a main concern of most builders and designers but they are not the only consideration in the design of new housing. Apart from aesthetics, the designer and owner are often interested in the environmental impact of a product or material. This report describes a calculator tool developed to combine cost aspects with sustainability impact aspects of roof cladding materials. The analysis considers costs, CO_2 gas emissions, embodied energy of cladding material, and the ability to recycle the material. Weights for each characteristic were used in the following combinations:

1. 100% LCC (sustainability factors not considered).
2. 70% LCC, 10% CO_2 gas emissions, 10% embodied energy of cladding material, 10% recyclability.
3. 40% LCC, 20% CO_2 gas emissions, 20% embodied energy of cladding material, 20% recyclability (an example of some green assessment schemes).

Contents

1. INTRODUCTION

Designers choose roof claddings mainly based on aesthetics, but what are the life cycle costs (LCC) and sustainability impacts of their choices? This report is on an Excel spreadsheet calculator tool, which provides LCC data for common claddings used on New Zealand dwellings. It also combines costs with sustainability impact factors, to which the user applies weights to give a total cost-sustainability score and the ability to rank selected claddings.

The Excel tool is an addition to the wall claddings calculator already on the BRANZ website and uses the same methodology. It uses standard LCC methods to calculate costs over the life of the materials. This is combined with sustainability impacts (embodied energy, CO_2 and recyclability) in a weighted evaluation process to give overall scores for claddings.

Included in the roof claddings tool is an option of choosing the house under moderate or severe/marine environmental conditions. The Appendix section outlines maintenance work for various roof cladding systems, environmental conditions definitions, sustainability factors, and the method of LCC. The default discount rate used is 5%.

For this report, a roof system is defined as the roofing components constructed after the rafters, for gable roofs below 30° pitch. Roofing components include, as required, wire netting, underlay, ridge and barge flashings, tile pointing, timber purlins, battens and plywood substrate. All these costs are accounted for in the initial costs for a roof claddings system. Costs included are the initial and maintenance costs only. Other roof types (higher pitched above 30° and flat roofs) are not analysed due to the lack of information on costs of these types.

Apart from liability, costs are the main concern of most builders and designers. They are likely to more heavily weigh than the other three components of the roof claddings systems Excel tool (CO_2, energy emissions and recyclability). In this report, analysis will be shown for the following weight scenarios for houses in the default moderate environmental conditions (refer to Appendix 6.3 for definition of environmental conditions):

1. 100% LCC (sustainability factors not considered).
2. 70% LCC, 10% CO_2 gas emissions, 10% embodied energy of cladding material, 10% recyclability.
3. 40% LCC, 20% CO_2 gas emissions, 20% embodied energy of cladding material, 20% recyclability (an example of some green assessment schemes).

Scenario 1 is in Section 3.1 *Life cycle cost analysis* and Scenarios 2 and 3 in Section 3.2 *Ranking of roof systems with the three sustainability factors considered.*

The main sources utilised are prices from Rawlinsons (2010) *NZ Construction Handbook* and Alcorn's (2003) *Embodied Energy and CO_2 Coefficients for NZ Building Materials*.

2. SUMMARY

2.1 Cost ranking of materials

The most cost-effective roof cladding systems, in terms of LCCs measured in annual cost per sqm, are corrugated steel and concrete and clay tiles. The latter two have longer cladding life spans than other claddings, which improves their life cost. Also, depending on the environmental conditions, concrete/clay tiles only require some maintenance (repointing every 20-25 years and painting every 25-30 years), whereas prepainted steel or metal tiles require painting every 7-10 years. All these affect the LCCs. Asphalt shingles and butyl membrane are the most expensive of the options considered, both initially and in LCC terms.

2.2 Ranking of materials with sustainability factors considered

Utilising the roof claddings tool, the top five cladding systems when costs are given a heavier weight than the other factors (LCC greater than 40%, the other factors 10-20% each), in no particular order are: concrete tiles, clay tiles, 0.4 mm prepainted steel corrugated/low rib, and unchipped painted metal tiles.

Concrete and clay tiles are among claddings with the lowest embodied energy and carbon emission content, and for this reason they rank among the top five roof claddings when given any weighting to LCC, carbon, energy emissions and recyclability factors.

3. MAIN RESULTS

This section is broken down into two parts:

1. LCC analysis, including sensitivity analysis of changing the discount rate.
2. Ranking of roof systems with sustainability factors considered (CO_2, embodied energy and recyclability).

3.1 LIFE CYCLE COST ANALYSIS

This section focuses on cost analysis only. Material and maintenance costs, and LCCs, are given in Tables 1 to 2 and are shown graphically in Figures 1 to 3. The analysis was carried out for two types of nominal environment, namely a moderate environment and a marine/severe environment. A definition of environmental conditions is included in the Appendix. The maintenance periods for severe/marine environments and the material life have been reduced by the factors given in Table 6.

The LCC has been expressed in the form of an equivalent annual cost. It consists of the initial cost, expressed in terms of annual payments (i.e. similar to mortgage payments), plus the maintenance costs converted into annual costs, as explained in Appendix 6.1. The reason for using annual costs rather than other alternatives, such as present value, is that the former automatically adjusts for the different life spans of the materials. If the present value measure was used then longer-life materials would have a bias toward higher present values, as maintenance is counted over a longer period than for short-life materials. The annual cost method also automatically allows for multiple replacements of the cladding system over the life of the building, since the initial cladding cost is spread over the total cladding life.

The discount rate allows for the time value of money, in which expenditure delayed until the future is worth less than expenditure required now. A base case real discount rate of 5% has been used, as discussed in the Appendix. Table 3 shows some results for other rates.

Initial costs of materials are from the Rawlinson (2010) *NZ Construction Handbook*, which was also used to derive most of the painting costs. Note that the costs include materials required to immediately support the cladding material. For roofs this includes purlins, battens, building paper and plywood sarking, as required.

Table 1. Life cycle assessment in a moderate environment

Life cycle costs of roof cladding systems													DISCOUNT RATE= 5.0%				
Moderate environment													**MAINTENANCE**		**INITIAL**	**TOTAL**	
	Initial Cost	**LIFE**	**MAINTENANCE (COSTS IN $/SQM)** 1		2		3		4		5		As a present	As an annual	As an annual	Annual	Rank
Roof Cladding	(1)	YRS	YR	CST	YR	CST	YR	CST	YR	CST	YR	CST	value	cost	cost	cost	
0.40mm Unpainted Steel sheet Corrugated	52	25											0.0	0.0	3.66	3.66	3
0.40mm Unpainted Steel sheet Low rib	61	25											0.0	0.0	4.3	4.30	12
0.40mm Unpainted Steel sheet High rib	63	25											0.0	0.0	4.4	4.44	14
0.40mm Unpainted Steel sheet Trough	66	25											0.0	0.0	4.7	4.66	18
0.40mm Prepainted steel Corrugated	58	50	15	12.0	25	11.0	35	11.0					11.0	0.6	3.2	3.76	4
0.40mm Prepainted steel Low rib	67	50	15	12.0	25	11.0	35	11.0					11.0	0.6	3.6	4.25	11
0.40mm Prepainted steel High rib	71	50	15	12.0	25	11.0	35	11.0					11.0	0.6	3.9	4.47	16
0.40mm Prepainted steel Trough	82	50	15	12.0	25	11.0	35	11.0					11.0	0.6	4.5	5.07	25
0.55mm Unpainted Steel sheet Corrugated	59	25											0.0	0.0	4.2	4.16	8
0.55mm Unpainted Steel sheet Low rib	69	25											0.0	0.0	4.9	4.87	22
0.55mm Unpainted Steel sheet High rib	69	25											0.0	0.0	4.9	4.87	22
0.55mm Unpainted Steel sheet Trough	69	25											0.0	0.0	4.9	4.87	22
0.55mm Prepainted steel Corrugated	65	50	15	12.0	25	11.0	35	11.0					11.0	0.6	3.5	4.14	7
0.55mm Prepainted steel Low rib	75	50	15	12.0	25	11.0	35	11.0					11.0	0.6	4.1	4.69	19
0.55mm Prepainted steel High rib	77	50	15	12.0	25	11.0	35	11.0					11.0	0.6	4.2	4.80	21
0.55mm Prepainted steel Trough	85	50	15	12.0	25	11.0	35	11.0					11.0	0.6	4.6	5.24	26
Aluminium 0.70 mm, no coat High rib	85	70											0.0	0.0	4.4	4.37	13
Aluminium 0.70 mm, no coat Corrugated	77	70											0.0	0.0	4.0	3.96	6
Aluminium 0.90 mm, no coat High rib	90	80											0.0	0.0	4.6	4.57	17
Aluminium 0.90 mm, no coat Corrugated	82	80											0.0	0.0	4.2	4.16	9
Metal tiles, Epoxy painted	60	50	15	12.0	25	11.0	35	11.0					11.0	0.6	3.3	3.90	5
Metal tiles, Epoxy painted, chip sealed	70	50	15	12.0	25	11.0	35	11.0					11.0	0.6	3.8	4.45	15
Metal tiles, Shakes painted	66	50	15	12.0	25	11.0	35	11.0					11.0	0.6	3.6	4.23	10
Metal tiles, Shakes painted, chip sealed	76	50	15	12.0	25	11.0	35	11.0					11.0	0.6	4.2	4.78	20
Asphalt shingles	125	20											0.0	0.0	10.0	10.03	28
Concrete tiles	61	90	25	4	30	9	45	4	60	9	65	4	4.4	0.2	3.1	3.32	1
Clay tiles	61	60	25	4	30	9	45	4					3.7	0.2	3.2	3.43	2
Butyl membrane 1mm	86	25											0.0	0.0	6.1	6.08	27

(1) initial costs is of typical roof system, defined as the roofing components constructed after the rafters, for gable roofs below 30 deg pitch. Roofing components include, if required , wire netting, underlay, ridge and barge flashings/tiles, pointing tiles, timber purlins, battens, plywood substrate

Table 1 shows concrete/clay tiles as the most cost-effective roof claddings systems, followed closely by 0.40 mm unpainted/prepainted corrugated steel, then non-chipped painted metal tiles. The most obvious reason for concrete/clay tiles being cost-effective is that they have longer life years than the other materials and therefore average out to have lower annual LCCs ($/sqm). Other factors also include painting less often than what is required for steel sheet or metal tile roofs. Asphalt shingles and butyl roof systems are the least cost-effective, due to the plywood substrate initial cost involved.

Figure 1. Initial versus annual costs $/sqm, moderate environment

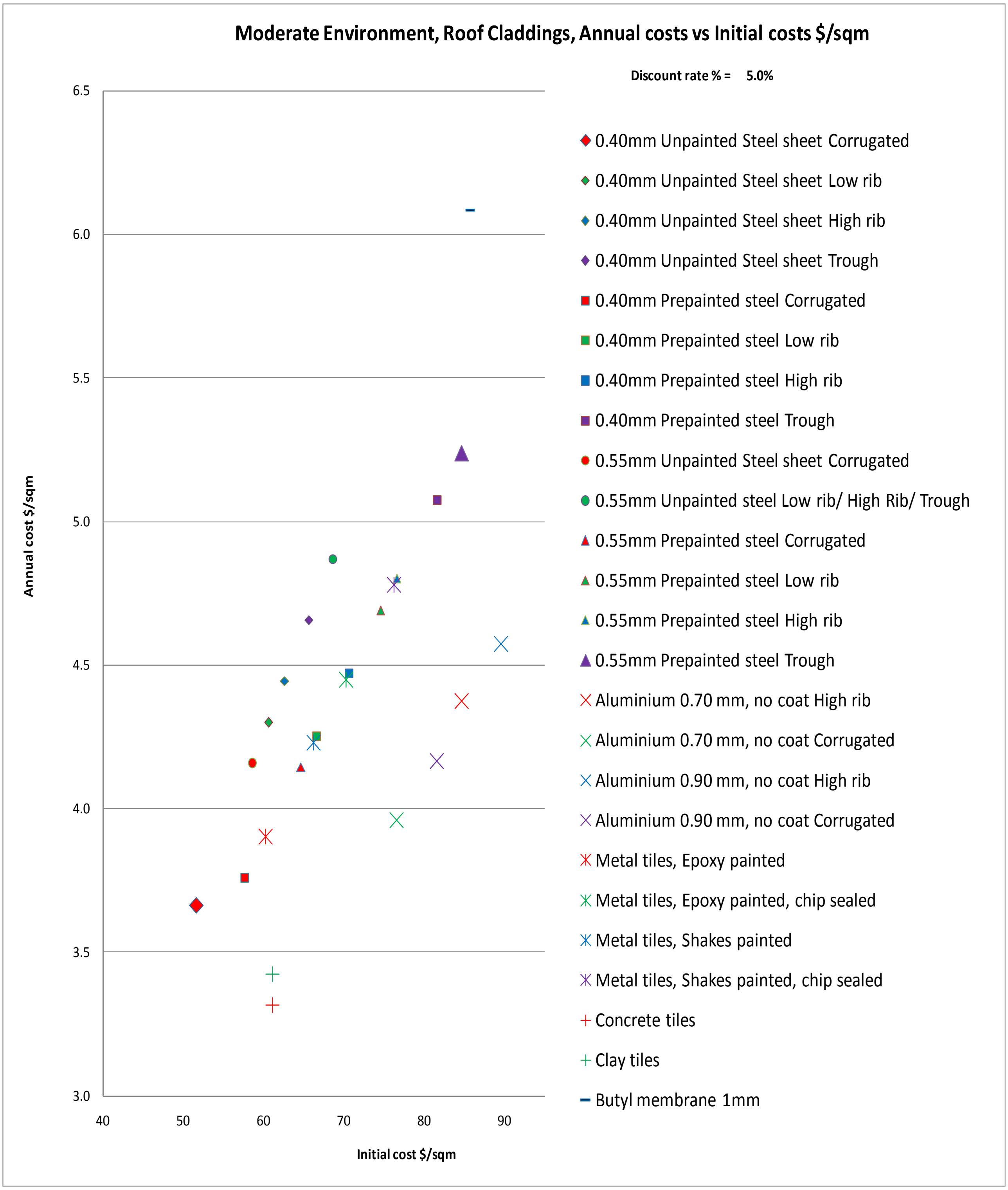


Figure 1 shows an approximate linear relationship between LCCs (annual cost $/sqm) and initial cost. However, the lowest initial costs of materials do not always have the lowest LCC. For example, concrete/clay tiles are more expensive than corrugated steel but the former has a lower annual LCC because they last longer with less maintenance.

Figure 2. Annual costs breakdown, maintenance and initial $/sqm, moderate environment

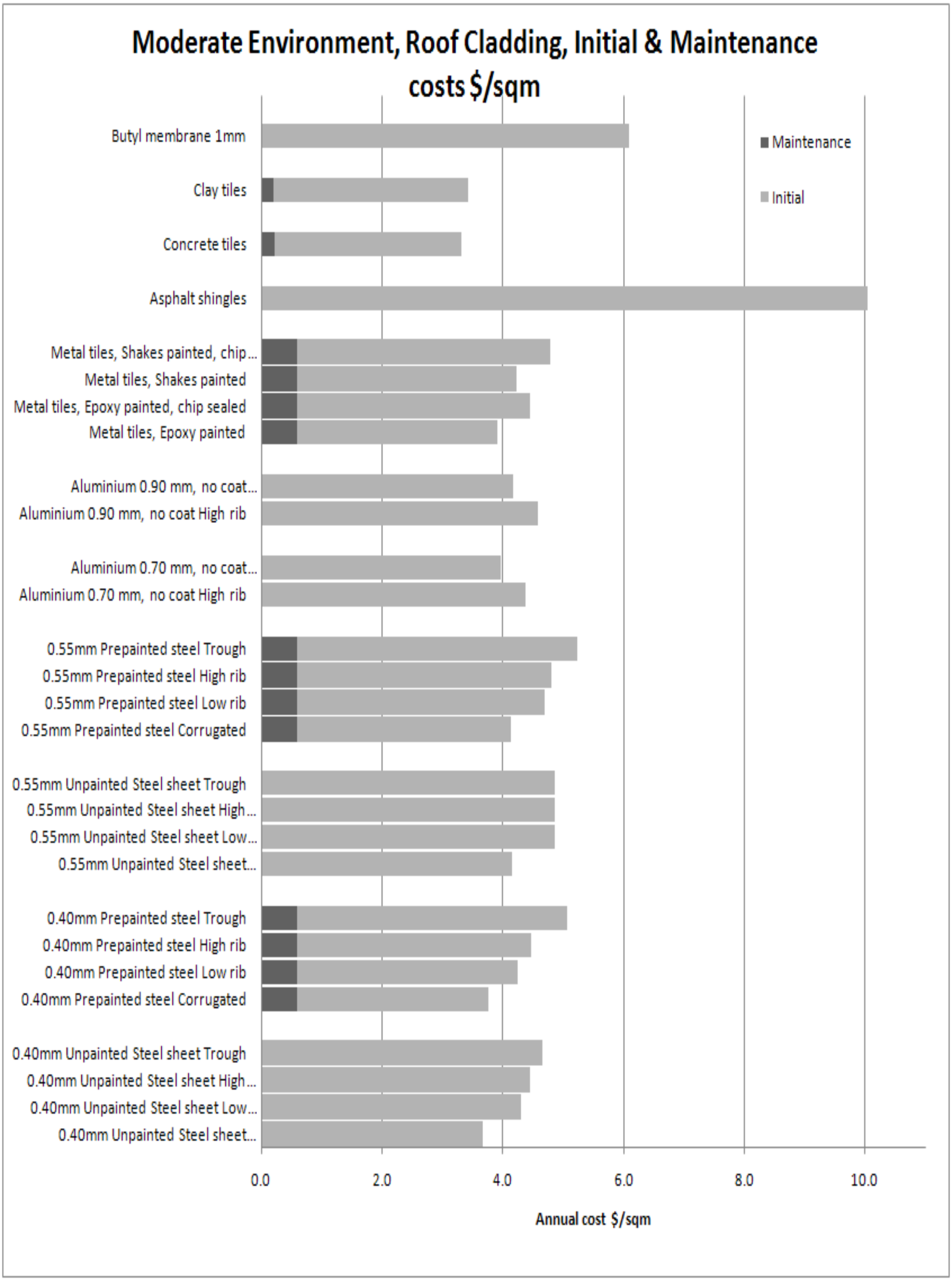


Figure 2 shows the proportion of maintenance and initial costs out of total $/sqm per annum. Prepainted steel, metal tiles and concrete/clay tiles have maintenance costs involved.

Table 2. Life cycle assessment in a severe/marine environment

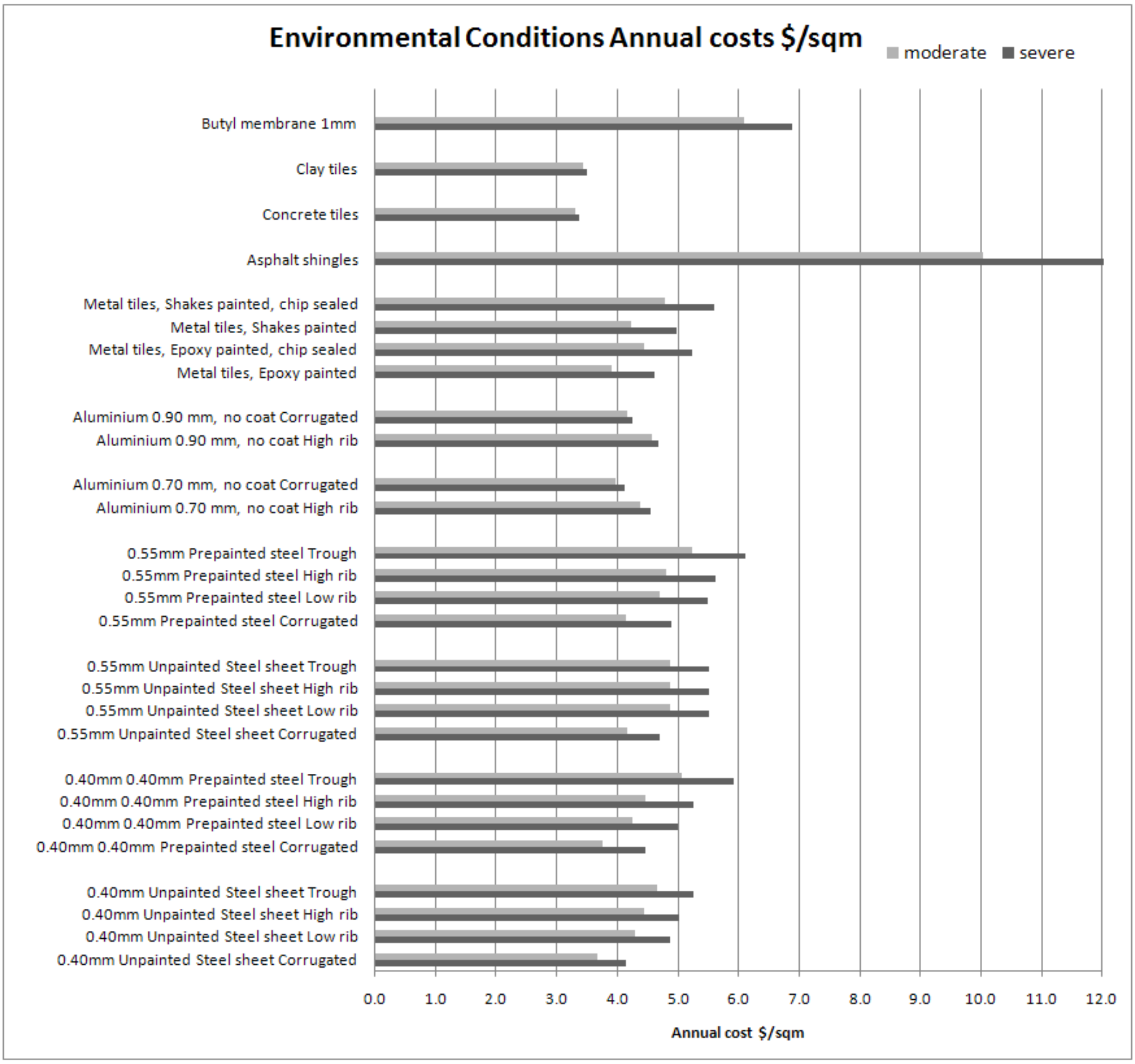
Life cycle costs of roof cladding systems DISCOUNT RATE= 5.0%

Severe/Marine environment

Roof Cladding	Initial Cost (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	MAINTENANCE As a present value	MAINTENANCE As an annual cost	INITIAL As an annual cost	TOTAL Annual cost	Rank
0.40mm Unpainted Steel sheet Corrugated	52	20											0.0	0.0	4.14	4.14	4
0.40mm Unpainted Steel sheet Low rib	61	20											0.0	0.0	4.9	4.86	11
0.40mm Unpainted Steel sheet High rib	63	20											0.0	0.0	5.0	5.02	15
0.40mm Unpainted Steel sheet Trough	66	20											0.0	0.0	5.3	5.27	18
0.40mm Prepainted steel Corrugated	58	35	10	12.0	18	11.0	25	11.0					15.4	0.9	3.5	4.46	6
0.40mm Prepainted steel Low rib	67	35	10	12.0	18	11.0	25	11.0					15.4	0.9	4.1	5.01	14
0.40mm Prepainted steel High rib	71	35	10	12.0	18	11.0	25	11.0					15.4	0.9	4.3	5.25	17
0.40mm Prepainted steel Trough	82	35	10	12.0	18	11.0	25	11.0					15.4	0.9	5.0	5.92	25
0.55mm Unpainted Steel sheet Corrugated	59	20											0.0	0.0	4.7	4.70	10
0.55mm Unpainted Steel sheet Low rib	69	20											0.0	0.0	5.5	5.51	20
0.55mm Unpainted Steel sheet High rib	69	20											0.0	0.0	5.5	5.51	20
0.55mm Unpainted Steel sheet Trough	69	20											0.0	0.0	5.5	5.51	20
0.55mm Prepainted steel Corrugated	65	35	10	12.0	18	11.0	25	11.0					15.4	0.9	3.9	4.89	12
0.55mm Prepainted steel Low rib	75	35	10	12.0	18	11.0	25	11.0					15.4	0.9	4.6	5.50	19
0.55mm Prepainted steel High rib	77	35	10	12.0	18	11.0	25	11.0					15.4	0.9	4.7	5.62	24
0.55mm Prepainted steel Trough	85	35	10	12.0	18	11.0	25	11.0					15.4	0.9	5.2	6.11	26
Aluminium 0.70 mm, no coat High rib	85	55											0.0	0.0	4.5	4.54	7
Aluminium 0.70 mm, no coat Corrugated	77	55											0.0	0.0	4.1	4.11	3
Aluminium 0.90 mm, no coat High rib	90	65											0.0	0.0	4.7	4.68	9
Aluminium 0.90 mm, no coat Corrugated	82	65											0.0	0.0	4.3	4.26	5
Metal tiles, Epoxy painted	60	35	10	12.0	18	11.0	25	11.0					15.4	0.9	3.7	4.62	8
Metal tiles, Epoxy painted, chip sealed	70	35	10	12.0	18	11.0	25	11.0					15.4	0.9	4.3	5.23	16
Metal tiles, Shakes painted	66	35	10	12.0	18	11.0	25	11.0					15.4	0.9	4.0	4.98	13
Metal tiles, Shakes painted, chip sealed	76	35	10	12.0	18	11.0	25	11.0					15.4	0.9	4.7	5.59	23
Asphalt shingles	125	15											0.0	0.0	12.0	12.04	28
Concrete tiles	61	80	25	4	27	9	41	4	54	9	59	4	5.0	0.3	3.1	3.38	1
Clay tiles	61	55	25	4	27	9	41	4					4.1	0.2	3.3	3.50	2
Butyl membrane 1mm	86	20											0.0	0.0	6.9	6.88	27

(1) initial costs is of typical roof system, defined as the roofing components constructed after the rafters, for gable roofs below 30 deg pitch. Roofing components include, if required , wire netting, underlay, ridge and barge flashings/tiles, pointing tiles, timber purlins, battens, plywood substrate

Figure 3. Moderate versus severe conditions, annual costs $/sqm



The effect of the environmental conditions from a moderate environment to a severe/marine one (refer to Appendix 6.3 and Table 6 for environmental conversion factors) is shown in Table 2 and Figure 3. The largest increases in annual LCCs, going from a moderate to severe environment, are for asphalt shingles, prepainted steel sheet and metal tiles. The increase in LCCs is between 17% to 20% in these materials. Unpainted steel and butyl membrane increase by around 13%. Concrete/clay and aluminium have smaller increases in costs, reflecting the greater stability of the base material under marine or severe environmental conditions, compared to the other materials. These results closely reflect the environmental factors used, with butyl, asphalt shingles and steel all having the lower factors than concrete/clay tiles. However, there will be situations where a lower factor could be applied for one or other of the materials, and this would increase the LCCs.

The analysis assumes that the severe environmental impact on a material is condensed into one factor, which has been applied to the moderate environment material life and maintenance return periods. This factor, between 0 and 1, is separate for each material, and it simplifies the calculation of LCCs (see Table 6). In effect, the assumption is that the impact of a severe environment can be allowed for by reducing the moderate environment material life and the period between maintenance, keeping other variables such as type and costs of maintenance unchanged.

This is obviously a simplification since an alternative, and possibly more likely, scenario is that in a severe environment maintenance would involve different initial and replacement coatings and procedures, and be to a higher quality than in the moderate environment. These alternative scenarios could be readily analysed in the current framework, but would involve collecting almost as much information again on durability and costs for the alternative initial surface finishes and maintenance regimes for severe environments and would not necessarily apply to all severe environments.

For unusually severe environments, it is suggested that the appropriate cost data be obtained for each particular case and a manual life cycle analysis be done for two or three tailor-made protective systems and maintenance regimes.

Table 3. Sensitivity analysis – annual costs at various discount rates

Annual costs $/sqm at various discount rates, moderate environment						
	discount rate			discount rate		
Roof Cladding	2.5%	5.0%	7.5%	2.5%	5.0%	7.5%
	Annual cost $/sqm			Rank		
0.40mm Unpainted Steel sheet Corrugated	2.8	3.7	4.6	9	3	1
0.40mm Unpainted Steel sheet Low rib	3.3	4.3	5.4	16	12	7
0.40mm Unpainted Steel sheet High rib	3.4	4.4	5.6	20	14	9
0.40mm Unpainted Steel sheet Trough	3.6	4.7	5.9	22	18	13
0.40mm Prepainted steel Corrugated	2.7	3.8	5.0	7	4	4
0.40mm Prepainted steel Low rib	3.0	4.3	5.7	12	11	11
0.40mm Prepainted steel High rib	3.2	4.5	6.0	14	16	15
0.40mm Prepainted steel Trough	3.5	5.1	6.8	21	25	25
0.55mm Unpainted Steel sheet Corrugated	3.2	4.2	5.3	15	8	6
0.55mm Unpainted Steel sheet Low rib	3.7	4.9	6.2	24	22	17
0.55mm Unpainted Steel sheet High rib	3.7	4.9	6.2	24	22	17
0.55mm Unpainted Steel sheet Trough	3.7	4.9	6.2	24	22	17
0.55mm Prepainted steel Corrugated	2.9	4.1	5.5	10	7	8
0.55mm Prepainted steel Low rib	3.3	4.7	6.3	17	19	20
0.55mm Prepainted steel High rib	3.4	4.8	6.4	19	21	23
0.55mm Prepainted steel Trough	3.6	5.2	7.0	23	26	26
Aluminium 0.70 mm, no coat High rib	2.6	4.4	6.4	5	13	21
Aluminium 0.70 mm, no coat Corrugated	2.3	4.0	5.8	3	6	12
Aluminium 0.90 mm, no coat High rib	2.6	4.6	6.7	6	17	24
Aluminium 0.90 mm, no coat Corrugated	2.4	4.2	6.1	4	9	16
Metal tiles, Epoxy painted	2.8	3.9	5.2	8	5	5
Metal tiles, Epoxy painted, chip sealed	3.1	4.4	5.9	13	15	14
Metal tiles, Shakes painted	3.0	4.2	5.6	11	10	10
Metal tiles, Shakes painted, chip sealed	3.4	4.8	6.4	18	20	22
Asphalt shingles	8.0	10.0	12.3	28	28	28
Concrete tiles	2.0	3.3	4.7	1	1	2
Clay tiles	2.2	3.4	4.8	2	2	3
Butyl membrane 1mm	4.7	6.1	7.7	27	27	27

In Table 3 above, the discount rate has been varied for roof cladding materials. The largest change in annual costs occurs in aluminium and concrete tiles, with a 60% reduction in costs, going from a discount rate of 7.5% to 2.5%. The lowest change is for asphalt shingles, which show a 35% change in annual costs. At 7.5%, unpainted steel sheets are more cost-effective, as concrete tiles with the higher discount rate penalise their long life and low maintenance costs. The future maintenance cost savings, compared to other materials, are therefore heavily discounted.

A base discount rate of 5% was chosen, as described in the Appendix. This is judged to be a reasonable estimate of the long-term real interest rate for home-owners over the next 10 years. Hence the upper and lower margins of the range of discount rates shown in the figures are unlikely to be reached in practice.

3.2 Ranking of roof systems with sustainability factors considered (CO_2, embodied energy and recyclability)

How much importance do builders/designers give to sustainability factors, and not just costs? BRANZ arbitrarily chose two other scaled combinations:

1. 70% LCC, 10% each for the three sustainability factors.
2. 40% LCC, 20% CO_2 gas emissions, 20% embodied energy of cladding material, 20% recyclability. This could be an example of a green assessment scheme.

Builders/designers/architects can enter their own preferences for the weights into the roof systems claddings calculator tool. This analysis is only for moderate environments. In every case, the lower the weighted or combined score, the better the ranking.

Table 4. 70% LCC, and 10% each for the three sustainability factors

Weight allocation % scenario	LCC 70	CO2 emissions 10	Emb energy 10	Recyclability 10		
Roof Cladding	weighted score	weighted score	weighted score	weighted score	Combined score	Rank
0.40mm Unpainted Steel sheet Corrugated	10	5	6	3	25	6
0.40mm Unpainted Steel sheet Low rib	16	5	6	3	31	10
0.40mm Unpainted Steel sheet High rib	18	6	7	3	33	16
0.40mm Unpainted Steel sheet Trough	20	6	7	3	36	20
0.40mm Prepainted steel Corrugated	11	2	4	3	20	3
0.40mm Prepainted steel Low rib	16	1	4	3	24	5
0.40mm Prepainted steel High rib	18	2	4	3	27	9
0.40mm Prepainted steel Trough	23	2	4	3	33	15
0.55mm Unpainted Steel sheet Corrugated	15	8	9	3	35	18
0.55mm Unpainted Steel sheet Low rib	22	8	8	3	41	24
0.55mm Unpainted Steel sheet High rib	22	8	9	3	42	25
0.55mm Unpainted Steel sheet Trough	22	9	10	3	43	26
0.55mm Prepainted steel Corrugated	15	3	5	3	26	8
0.55mm Prepainted steel Low rib	20	3	5	3	31	11
0.55mm Prepainted steel High rib	21	3	5	3	32	14
0.55mm Prepainted steel Trough	25	3	6	3	37	22
Aluminium 0.70 mm, no coat High rib	17	8	8	2	35	19
Aluminium 0.70 mm, no coat Corrugated	13	9	9	2	32	13
Aluminium 0.90 mm, no coat High rib	19	9	9	2	39	23
Aluminium 0.90 mm, no coat Corrugated	15	10	10	2	36	21
Metal tiles, Epoxy painted	13	2	4	4	22	4
Metal tiles, Epoxy painted, chip sealed	18	4	5	4	31	12
Metal tiles, Shakes painted	16	2	4	4	25	7
Metal tiles, Shakes painted, chip sealed	21	4	6	4	34	17
Asphalt shingles	70	3	5	10	89	28
Concrete tiles	7	0	1	6	14	1
Clay tiles	8	1	3	7	19	2
Butyl membrane 1mm	33	4	7	10	54	27

Table 4 above shows the top four roof systems from this allocation scenario are: 0.40 mm prepainted corrugated steel, painted non-chip sealed metal tiles, concrete tiles, and clay tiles.

Table 5. 40% LCC, 20% CO_2 gas emissions, 20% embodied energy of cladding material, 20% recyclability

	Weight allocation % scenario					
	LCC	CO2 emissions	Emb energy	Recyclability		
	40	20	20	20		
Roof Cladding	weighted score	weighted score	weighted score	weighted score	Combined score	Rank
0.40mm Unpainted Steel sheet Corrugated	6	11	13	6	35	12
0.40mm Unpainted Steel sheet Low rib	9	10	13	6	38	14
0.40mm Unpainted Steel sheet High rib	10	11	14	6	41	17
0.40mm Unpainted Steel sheet Trough	11	13	15	6	44	18
0.40mm Prepainted steel Corrugated	6	3	8	6	24	2
0.40mm Prepainted steel Low rib	9	3	8	6	26	3
0.40mm Prepainted steel High rib	10	4	8	6	28	6
0.40mm Prepainted steel Trough	13	4	9	6	32	9
0.55mm Unpainted Steel sheet Corrugated	9	16	17	6	48	21
0.55mm Unpainted Steel sheet Low rib	12	15	17	6	50	22
0.55mm Unpainted Steel sheet High rib	12	17	18	6	53	25
0.55mm Unpainted Steel sheet Trough	12	18	20	6	56	26
0.55mm Prepainted steel Corrugated	8	6	10	6	31	8
0.55mm Prepainted steel Low rib	11	5	10	6	33	10
0.55mm Prepainted steel High rib	12	6	11	6	35	11
0.55mm Prepainted steel Trough	14	7	11	6	39	16
Aluminium 0.70 mm, no coat High rib	10	16	17	3	45	19
Aluminium 0.70 mm, no coat Corrugated	7	17	18	3	46	20
Aluminium 0.90 mm, no coat High rib	11	18	19	3	51	23
Aluminium 0.90 mm, no coat Corrugated	9	20	20	3	52	24
Metal tiles, Epoxy painted	7	4	8	8	26	4
Metal tiles, Epoxy painted, chip sealed	10	7	11	8	37	13
Metal tiles, Shakes painted	9	4	8	8	28	7
Metal tiles, Shakes painted, chip sealed	12	7	11	8	38	15
Asphalt shingles	40	7	11	20	78	28
Concrete tiles	4	0	2	12	18	1
Clay tiles	5	3	6	14	27	5
Butyl membrane 1mm	19	9	13	20	61	27

Table 5 above shows the top four systems remain the roughly same as the previous scenario (apart from clay tiles)

4. DISCUSSION

4.1 Cost ranking of materials

The most cost-effective roof cladding systems, in terms of LCCs measured in annual cost per sqm, are concrete and clay tiles. The main reasons include concrete/clay tiles having a longer cladding life span. Also, depending on the environmental conditions, concrete/clay tiles only require some maintenance (repointing every 20-25 years and painting every 25-30 years), whereas prepainted steel or metal tiles require painting every 7-10 years after the initial nil maintenance period. All these affect the LCCs.

The initial cost of a cladding material is a major variable in LCC analysis. Generally, but not always, cheaper materials have lower LCCs. Often other considerations apart from cost (such as aesthetics) will govern the choice of material and the maintenance regime, and LCC analysis quantifies the cost implications of those decisions.

4.2 Ranking of materials with sustainability factors considered

Utilising the roof claddings tool, the top five cladding systems when costs are given a heavier weight than the other factors (greater than 40%, the other factors 10-20% each), in no particular order are: concrete tiles, clay tiles, 0.4 mm prepainted steel corrugated/low rib, and unchipped painted metal tiles.

Concrete and clay tiles have the lowest embodied energy and carbon emission content, and for this reason they rank among the top five roof claddings when given any weighting to LCC, carbon, energy emissions and recyclability factors.

4.3 Salvage and disposal costs

These costs have been ignored in the analysis, partly due to the lack of data but mainly because their effect on LCCs is likely to be small.

4.4 Variability

The analysis has used or assumed average values for durability of materials, exposure conditions and quality of workmanship. However there will in practice be some variation in:

- durability of similar materials from different manufacturers and between different batches from the same manufacturer
- quality of initial installation and the actual construction regime used
- quality of maintenance
- exposure conditions, which will be spread over a range of conditions rather than the two states analysed.

These possible causes of variation have not been analysed but LCCs could be significantly affected to a greater or lesser extent, depending on the material. For example, materials which are dependent on well-controlled maintenance and/or installation procedures, such as corrugated steel roofs, could have higher than expected maintenance costs and shorter lives if the work is not carried out correctly.

5. REFERENCES

Alcorn A. 2003. *Embodied Energy and CO_2 Coefficients for NZ Building Materials*. Centre for Building Performance Research, Victoria University of Wellington, Wellington, NZ.

Australian/New Zealand Standard AS/NZS 2312.

Page I. 1997. '*Life Cycle Costs of Claddings'. BRANZ Study Report 75*. BRANZ Ltd, Judgeford, NZ.

Rawlinsons. 2010. *NZ Construction Handbook*. Rawlinsons Ltd, Auckland, NZ.

6. APPENDIX

6.1 Life cycle cost analysis

The principles of LCC analysis are well known. 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:

$$(1 + r)^5 = 1.611 \text{ for } r=10\%$$

Hence, 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:

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

Where PV = present value of the future cost streams \$/sqm:

C_i = initial cost of material \$/sqm.
C_1 , C_2 , C_3, C_N = maintenance costs, \$/sqm, in years 1, 2, 3 ... N
r = discount rate
N = life of material

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

$$A = PV * CRF \qquad \text{Equation 2.}$$

Where A = annual equivalent LCC \$/sqm
CRF(r/N) = capital recovery factor for N years and discount rate r

$$CRF(r/N) = r(1+r)^N/((1+r)^N-1) \qquad \text{Equation 3.}$$

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 domestic buildings the relevant rate is the cost of finance to the home owner, namely the mortgage rate. 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 interest rate used is the long-term, inflation-adjusted interest rate and is estimated to be around 5%. This is based on an assumed average 10-year Government stock rate of 5.5%. To this is added a 2.5% risk factor for home mortgages less an average inflation rate over the next few years of 3% per annum, giving a 5.0% real mortgage rate for the next few years.

6.2 Sustainability factors: embodied energy, CO_2 and recyclability

Roof Cladding	Life years of cladding		Initial embodied energy				Maintenance emb energy	Total emb energy	Carbon dioxide emissions			Recyclability
	Moderate Life Years	Severe Life Years	kg/sqm	MJ/kg	MJ/sqm	MJ/sqm/yr	MJ/sqm/yr	Initial + maintenance MJ/sqm/yr	g CO2/kg	Ratio CO2 to ee	g CO2/sqm/yr	Scale lower is better
0.40mm Unpainted Steel sheet Corrugated	25	20	4.7	31.3	146	5.8	0.00	5.8	1243	40	232	30
0.40mm Unpainted Steel sheet Low rib	25	20	4.5	31.3	141	5.6	0.00	5.6	1243	40	224	30
0.40mm Unpainted Steel sheet High rib	25	20	4.9	31.3	153	6.1	0.00	6.1	1243	40	243	30
0.40mm Unpainted Steel sheet Trough	25	20	5.2	31.3	164	6.5	0.00	6.5	1243	40	260	30
0.40mm Prepainted steel Corrugated	50	35	4.7	31.3	160	3.2	0.70	3.9	1242	40	116	30
0.40mm Prepainted steel Low rib	50	35	4.5	31.3	155	3.1	0.70	3.8	1242	40	112	30
0.40mm Prepainted steel High rib	50	35	4.9	31.3	167	3.3	0.70	4.0	1242	40	121	30
0.40mm Prepainted steel Trough	50	35	5.2	31.3	178	3.6	0.70	4.3	1242	40	130	30
0.55mm Unpainted Steel sheet Corrugated	25	20	6.3	31.3	196	7.9	0.00	7.9	1243	40	312	30
0.55mm Unpainted Steel sheet Low rib	25	20	6.1	31.3	190	7.6	0.00	7.6	1243	40	302	30
0.55mm Unpainted Steel sheet High rib	25	20	6.6	31.3	206	8.2	0.00	8.2	1243	40	327	30
0.55mm Unpainted Steel sheet Trough	25	20	7.0	31.3	220	8.8	0.00	8.8	1243	40	349	30
0.55mm Prepainted steel Corrugated	50	35	6.3	31.3	210	4.2	0.70	4.9	1242	40	156	30
0.55mm Prepainted steel Low rib	50	35	6.1	31.3	204	4.1	0.70	4.8	1242	40	151	30
0.55mm Prepainted steel High rib	50	35	6.6	31.3	220	4.4	0.70	5.1	1242	40	163	30
0.55mm Prepainted steel Trough	50	35	7.0	31.3	234	4.7	0.70	5.4	1242	40	175	30
Aluminium 0.70 mm, no coat High rib	70	55	2.7	192.0	526	7.5	0.00	7.5	8000	42	313	15
Aluminium 0.70 mm, no coat Corrugated	70	55	2.9	192.0	560	8.0	0.00	8.0	8000	42	333	15
Aluminium 0.90 mm, no coat High rib	80	65	3.5	192.0	674	8.4	0.00	8.4	8000	42	351	15
Aluminium 0.90 mm, no coat Corrugated	80	65	3.8	192.0	721	9.0	0.00	9.0	8000	42	375	15
Metal tiles, Epoxy painted	50	35	4.9	31.3	168	3.4	0.35	3.7	1242	40	122	40
Metal tiles, Epoxy painted, chip sealed	50	35	7.3	31.3	243	4.9	0.35	5.2	1242	40	182	40
Metal tiles, Shakes painted	50	35	5.0	31.3	171	3.4	0.35	3.8	1242	40	125	40
Metal tiles, Shakes painted, chip sealed	50	35	7.3	31.3	244	4.9	0.35	5.2	1242	40	182	40
Asphalt shingles	20	15	11.8	8.3	98	4.9	0.00	4.9	291	35	171	100
Concrete tiles	90	80	53.0	0.9	48	0.5	0.35	0.9	114	127	67	60
Clay tiles	60	55	47.0	2.7	127	2.1	0.35	2.5	138	51	108	70
Butyl membrane 1mm	25	20	1.2	120	149	6.0	0.00	6.0	4020	34	199	100

This table shows embodied energy (both initial and maintenance), carbon coefficients, and a recyclability scale where lower values are better. Concrete and clay tiles have the lowest embodied energy and carbon content. Aluminium is the most recyclable material.

The highlighted columns Embodied energy MJ per sqm over the life years of the cladding material, CO_2 grams per sqm over the life years of the cladding material, and cladding recyclability scale between 1 to 100 where lower is better, are the ones which influence the overall score of the roof systems calculator tool.

The sources which compiled the majority of the information for the above table includes Alcorn's (2003) *Embodied Energy and CO_2 Coefficients for NZ Building Materials*. Recyclability values were derived in discussion with scientists in the BRANZ Durability Group and are estimates only.

Embodied energy is defined as fossil fuels used in work to make any product, bring it to market, and dispose of it. Embodied energy is a methodology which aims to find the sum total of the energy necessary for an entire product life cycle. This life cycle includes raw material extraction, transport, manufacture, assembly, installation, disassembly, deconstruction and/or decomposition. The values in the table are for the life cycle process up to and including manufacture and maintenance. Assembly and deconstruction are not included. Carbon dioxide emissions are about the amount of carbon dioxide released into the atmosphere during the processes up to and including manufacture and maintenance.

6.3 Environmental conditions

The definitions of environmental conditions (defined by how the materials perform) are:

Metal substrate – as defined in AS/NZS 2312. Moderate conditions are a mild steel first-year corrosion rate of between 10 to 25μm per annum. Much of New Zealand is within this zone, which can be described as lightly marine influenced. A marine environment is a mild steel corrosion rate of 25 to 50μm per annum and is usually within a few hundred metres of the coastline. For the purposes of this study it also includes industrial areas and geothermal zones involving chemical discharges to the atmosphere.

Concrete – no particular agreed measure is available but two main factors influence the performance of the substrate and its coatings, namely moisture and temperature. For the purposes of this study it is assumed that most of New Zealand lies within the moderate zone and it is only regions of high relative humidity, over 83%, 9 am annual average, or which have over 2000 mm of rainfall per year, that are in the severe environment.

Butyl membrane, asphalt shingles – no particular agreed measure is available but performance is largely governed by the degree of exposure to UV radiation. Peak temperatures are also important. UV radiation decreases with an increase in latitude and increases with an increase in altitude. Most of the country is in a moderate environment but alpine areas and northern locations with high summer temperatures, such as inland Bay of Plenty or Hawke's Bay, or lower latitudes with higher UV in the upper half of the North Island, are probably in a severe environment.

The LCCs under severe environmental conditions, i.e. severe/marine environment impacts, were derived from the moderate case with a one factor adjustment to the time periods. This adjustment factor was a number between 0 and 1 and was applied to the maintenance return period and the life of the material. It is assumed to represent all the increased environmental impacts of a marine/severe environment. The factors are shown in Table 6. They are not based on any particular specific systematic research, but are broad estimates based on BRANZ experience over the past 25 years of researching the durability of materials under various conditions.

Table 6. Environmental adjustment factors

Environmental Factor		
Substrata	Factor (1)	Governing impact
Concrete/Clay	0.9	Moisture/shade
Steel	0.7	Marine salts
Aluminium	0.8	Marine salts
Buytl	0.7	UV radiation/temperature
Asphalt	0.8	UV radiation/temperature
(1) The factor is applied to the moderate environment material life and maintenance return periods to give the marine/severe environment life and maintenance periods. It is an approximation of average effects and will vary widely between uses of the same material.		

For example, the prepainted steel roofs in a severe environment have a life of 35 years, and maintenance costs of $11/sqm at year 10, year 18, and year 25. Under moderate conditions the life is 50 years and the maintenance is unchanged at $11/sqm at years 15, 25 and 35. These values are obtained by using the steel environmental factor from Table 6 and multiplying it by the maintenance periods and cladding life given in Table 7 and Table 8 for prepainted steel roofing (maintenance work tables on next page).

6.4 Maintenance

Descriptions of claddings maintenance and periods, and material lives, for moderate and marine/severe environments, are shown below in Tables 7 and 8. They were derived in discussion with scientists in the BRANZ Durability Group and are estimates only.

Table 7. Roof maintenance in moderate conditions

Life cycle costs of roof cladding systems	MODERATE ENVIRONMENT
Environmental condition =	**m**
Roof Cladding	**TYPE OF WORK, MAINTENANCE INTERVAL AND LIFE SPAN**
0.40mm Unpainted Steel sheet Corrugated	Do not paint. Replace at 25 years.
0.40mm Unpainted Steel sheet Low rib	Do not paint. Replace at 25 years.
0.40mm Unpainted Steel sheet High rib	Do not paint. Replace at 25 years.
0.40mm Unpainted Steel sheet Trough	Do not paint. Replace at 25 years.
0.40mm Prepainted steel Corrugated	Repaint after 15 years, every 10 years thereafter. Replace at 50 years.
0.40mm Prepainted steel Low rib	Repaint after 15 years, every 10 years thereafter. Replace at 50 years.
0.40mm Prepainted steel High rib	Repaint after 15 years, every 10 years thereafter. Replace at 50 years.
0.40mm Prepainted steel Trough	Repaint after 15 years, every 10 years thereafter. Replace at 50 years.
0.55mm Unpainted Steel sheet Corrugated	Do not paint. Replace at 25 years.
0.55mm Unpainted Steel sheet Low rib	Do not paint. Replace at 25 years.
0.55mm Unpainted Steel sheet High rib	Do not paint. Replace at 25 years.
0.55mm Unpainted Steel sheet Trough	Do not paint. Replace at 25 years.
0.55mm Prepainted steel Corrugated	Repaint after 15 years, every 10 years thereafter. Replace at 50 years.
0.55mm Prepainted steel Low rib	Repaint after 15 years, every 10 years thereafter. Replace at 50 years.
0.55mm Prepainted steel High rib	Repaint after 15 years, every 10 years thereafter. Replace at 50 years.
0.55mm Prepainted steel Trough	Repaint after 15 years, every 10 years thereafter. Replace at 50 years.
Aluminium 0.70 mm, no coat High rib	Do not paint. Replace at 70 years.
Aluminium 0.70 mm, no coat Corrugated	Do not paint. Replace at 70 years.
Aluminium 0.90 mm, no coat High rib	Do not paint. Replace at 80 years.
Aluminium 0.90 mm, no coat Corrugated	Do not paint. Replace at 80 years.
Metal tiles, Epoxy painted	Repaint after 15 years, every 10 years thereafter. Replace at 50 years.
Metal tiles, Epoxy painted, chip sealed	Repaint after 15 years, every 10 years thereafter. Replace at 50 years.
Metal tiles, Shakes painted	Repaint after 15 years, every 10 years thereafter. Replace at 50 years.
Metal tiles, Shakes painted, chip sealed	Repaint after 15 years, every 10 years thereafter. Replace at 50 years.
Asphalt shingles	No maintenence req. Life 20 years
Concrete tiles	pointing/ridges after 25 years, every 20 years thereafter. Paint after 30 years. Life 90 years.
Clay tiles	pointing/ridges after 25 years, every 20 years thereafter. Paint after 30 years. Life 60 years.
Butyl membrane 1mm	No maintenence req. Life 25 years

Table 8. Roof maintenance in severe/marine conditions

Life cycle costs of roof cladding systems	SEVERE / MARINE ENVIRONMENT
Environmental condition =	**s**
Roof Cladding	**TYPE OF WORK, MAINTENANCE INTERVAL AND LIFE SPAN**
0.40mm Unpainted Steel sheet Corrugated	Do not paint. Replace at 20 years.
0.40mm Unpainted Steel sheet Low rib	Do not paint. Replace at 20 years.
0.40mm Unpainted Steel sheet High rib	Do not paint. Replace at 20 years.
0.40mm Unpainted Steel sheet Trough	Do not paint. Replace at 20 years.
0.40mm Prepainted steel Corrugated	Repaint after 10 years, every 7 years thereafter. Replace at 35 years.
0.40mm Prepainted steel Low rib	Repaint after 10 years, every 7 years thereafter. Replace at 35 years.
0.40mm Prepainted steel High rib	Repaint after 10 years, every 7 years thereafter. Replace at 35 years.
0.40mm Prepainted steel Trough	Repaint after 10 years, every 7 years thereafter. Replace at 35 years.
0.55mm Unpainted Steel sheet Corrugated	Do not paint. Replace at 20 years.
0.55mm Unpainted Steel sheet Low rib	Do not paint. Replace at 20 years.
0.55mm Unpainted Steel sheet High rib	Do not paint. Replace at 20 years.
0.55mm Unpainted Steel sheet Trough	Do not paint. Replace at 20 years.
0.55mm Prepainted steel Corrugated	Repaint after 10 years, every 7 years thereafter. Replace at 35 years.
0.55mm Prepainted steel Low rib	Repaint after 10 years, every 7 years thereafter. Replace at 35 years.
0.55mm Prepainted steel High rib	Repaint after 10 years, every 7 years thereafter. Replace at 35 years.
0.55mm Prepainted steel Trough	Repaint after 10 years, every 7 years thereafter. Replace at 35 years.
Aluminium 0.70 mm, no coat High rib	Do not paint. Replace at 55 years.
Aluminium 0.70 mm, no coat Corrugated	Do not paint. Replace at 55 years.
Aluminium 0.90 mm, no coat High rib	Do not paint. Replace at 65 years.
Aluminium 0.90 mm, no coat Corrugated	Do not paint. Replace at 65 years.
Metal tiles, Epoxy painted	Repaint after 10 years, every 7 years thereafter. Replace at 35 years.
Metal tiles, Epoxy painted, chip sealed	Repaint after 10 years, every 7 years thereafter. Replace at 35 years.
Metal tiles, Shakes painted	Repaint after 10 years, every 7 years thereafter. Replace at 35 years.
Metal tiles, Shakes painted, chip sealed	Repaint after 10 years, every 7 years thereafter. Replace at 35 years.
Asphalt shingles	No maintenence req. Life 15 years
Concrete tiles	pointing/ridges after 25 years, every 20 years thereafter. Paint after 25 years. Life 80 years.
Clay tiles	pointing/ridges after 25 years, every 20 years thereafter. Paint after 25 years. Life 55 years.
Butyl membrane 1mm	No maintenence req. Life 20 years