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Energy and carbon dioxide implications of building construction

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Abstract

This paper investigates the amount of energy required to construct buildings, and the resulting carbon dioxide emissions to the atmosphere from the fossil fuel components of that energy. Energy requirements and carbon dioxide emissions are compared for typical commercial, industrial and residential buildings, using New Zealand as an example. A modest change from concrete and steel to more wood construction could lead to a substantial reduction in energy requirements and carbon dioxide emissions, but the sustainability of such a change has significant forestry implications.

Introduction

Selection of building materials

This paper has resulted from a growing awareness that in the choice of building materials, the designer must consider not only the requirements of the building owner and occupier, but also the resource base and the effects of extraction, manufacture and processing of building materials on the social and natural environment of this planet.

The greenhouse effect

Human activity has increased the levels of certain 'greenhouse' gases in the atmosphere. These retain some of the sun's heat in the atmosphere by absorbing infra-red radiation that is otherwise reflected back into space. Greenhouse gases include water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), tropospheric ozone (O_3) and chlorofluorocarbons (CFCs). Of these gases, CO_2 is the most important by-product of the manufacture of building materials.

There is scientific debate about the global temperature increases which could result from increasing concentrations of greenhouse gases, but there is no doubt that a large uncontrolled experiment is being conducted on the earth's atmosphere, the results of which will not be known until it is too late to turn back the clock.

Air temperatures around the world have risen by about 0.5 °C during the last 50 years and this warming trend is expected to accelerate if nothing is accomplished to reduce greenhouse gas emissions. Sea-levels may rise as a result of thermal expansion in the oceans and the melting of glaciers and ice sheets brought about by a global climate change. Intensity in weather extremes is expected to increase.

Long-term global reductions in CO_2 emissions will only be possible with a massive move to solar and other renewable energy sources and a major reduction in fossil fuel combustion, combined with a reduction in per capita energy use through conservation and other measures. One strategy for reducing fossil fuel use is to increase the use of less energy-intensive materials. This paper considers the impact of the construction industry on CO_2 emissions and identifies a small but significant reduction in fossil fuel combustion which would result from increased use of timber as an engineering material, using New Zealand as a case study.

New Zealand

New Zealand is a small country in the South Pacific, with a land area of 270 000 square kilometres and a population of 3.5 million people.

Nearly one quarter of the land area is covered with indigenous forest which is not used significantly for wood production. Fast-growing plantation forests cover 4% of the land area (1.2 million hectares), supplying a large and expanding timber industry.

In New Zealand, CO_2 is the main greenhouse gas, but its effect is closely followed by those of methane and nitrous oxide, both of which mainly result from agricultural activities. Almost half of New Zealand's CO_2 emissions result from transport, followed by

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industrial and commercial activities [1]. New Zealand emits approximately 6 million tonnes of carbon, as carbon dioxide, to the atmosphere each year. Of this, 90% is from fossil fuel combustion [1]. Note that in this paper, CO_2 emissions are quantified in tonnes of carbon, not carbon dioxide.

Background document

This paper is a summary of a recent report by Honey and Buchanan [1], which should be consulted for the derivation of figures, background discussion, and an extensive list of references.

Energy to manufacture building materials

Energy coefficients

This paper uses energy coefficients of building materials to estimate the total energy required to manufacture various buildings, and the resulting emissions of CO_2 to the atmosphere. The main source of energy coefficients is a report by Baird and Chan [2] who estimated the energy requirements for all major building materials, and for house construction in New Zealand. Minor additions to their data have been made by Honey and Buchanan [1].

The resulting figures are shown in Appendix 1, with a summary for a few main materials in Table 1. Most of the energy estimates are based on published statistics from various countries, some of which are contradictory. It is difficult to obtain precise estimates for many reasons, including the following:

(1) Industrial processes and economic activities vary widely between countries. Less developed countries tend to have less efficient processes.

(2) Industrial energy usage is process-specific. Modern factories are generally far more energy-efficient than older ones, as a result of recent concerns about energy efficiency and CO_2 emissions. The figures used here are intended to be representative figures for the current global mix of processes.

TABLE 1. Energy required to manufacture common building materials

	Energy		Density kg/m³
	GJ/t	GJ/m³	
Treated timber	2.4	1.2	500
Glue laminated timber	9	4.5	500
Structural steel	59	448	7600
Reinforced concrete	3.1	7.3	2400
Aluminium	145	362	2500

(3) There are many differences in raw materials, efficiencies of labour, treatment of waste products, and levels of recycling.

A thorough energy analysis must include not only the direct process energy, but also the energy required to make the machines and generate the capital necessary for the process to be established.

The right-hand column in Appendix 1 shows the level to which the energy coefficients have been evaluated, using the scale below:

Level 1 — the direct and transport energy inputs to the process.

Level 2 — the energy required to make the material inputs to the process is included.

Level 3 — the energy required to generate the capital for the process is included.

Level 4 — this includes the energy required to make the machines that make the machines.

Fossil fuel energy

In order to calculate CO_2 emissions from energy consumption, it is necessary to know how much of the energy is obtained from burning of fossil fuels. Energy obtained from direct solar energy, geothermal energy or nuclear fission does not result in CO_2 emissions (except for fossil fuel used to manufacture or operate the power stations).

Energy from burning of wood or other biomass is not included because that is simply a release of solar energy stored in the wood when the tree was growing. Fossil fuel energy is also stored solar energy, but the differing time scales of storage and release of the energy are not sustainable in the way that wood or biomass energy is.

For New Zealand, the proportions of each type of energy are shown in Appendix 1. For other countries, the energy figures used in this paper will generally be similar, but the mix of energy sources may vary considerably. This could lead to very different conclusions for a country where much more or much less of the energy is obtained from burning fossil fuels.

The 'capital' and 'imports' figures are assumed to be divided between each fuel type in the same proportions as the New Zealand input, for lack of any better information.

Carbon dioxide emissions

The fossil fuel components of energy described above can be used to calculate the CO_2 emissions resulting from the manufacture of building materials.

To obtain carbon coefficients from energy intensities, the fossil fuel energy components (that is, energy from gas, oil, coal and the proportion of electricity generated from fossil fuel) are each multiplied by a factor of 0.02 kg C/MJ. This figure was derived [3] from reported world consumption of 260 000 PJ of fossil fuel releasing 5.2 billion tonnes of carbon in 1984 [4]. A more recent report [5] gives 0.013 kg carbon per MJ of energy, but the figure of 0.02 kg C/MJ has been used here.

Additional carbon releases which occur during the manufacture of aluminium and cement must be added to the carbon coefficients. The resulting carbon coefficients are shown in Appendix 2.

Two scenarios are given. The first is based on the current New Zealand situation, where 75% of the electricity is generated from hydropower stations and the remainder from fossil fuel thermal power stations. Both scenarios assume that thermal electricity generation is 33% efficient. The second scenario assumes that all electricity is generated from fossil fuel power stations. Fossil fuel power stations are the main source of the world's electricity, producing 66% of the world total [4].

The Scenario 1 figures give a picture of current usage in New Zealand, but the Scenario 2 figures are useful because thermal power stations are used in New Zealand to meet peak demand. For this reason, any changes in the energy requirements of building construction are more likely to result in changes in the demand for thermal electricity than hydroelectricity. The figures quoted elsewhere in this paper are all for Scenario 1.

Table 2 gives quantities of carbon emitted in the manufacture of a few common building materials. The figures in the right hand column of Table 2 are plotted in Fig. 1, which shows that steel and aluminium emit far more CO_2 in their manufacture than reinforced concrete. Timber products have negative values because the carbon 'locked up' in the material is greater than that emitted during processing.

TABLE 2. Carbon emissions resulting from manufacture of common building materials

	Carbon Released		Carbon stored kg/m³	Nett carbon emitted kg/m³
	kg/t	kg/m³		
Treated timber	44	22	250	-228
Glue laminated timber	164	82	250	-168
Structural steel	1070	8132	15	8117
Reinforced concrete	76	182	0	182
Aluminium	2530	6325	0	6325

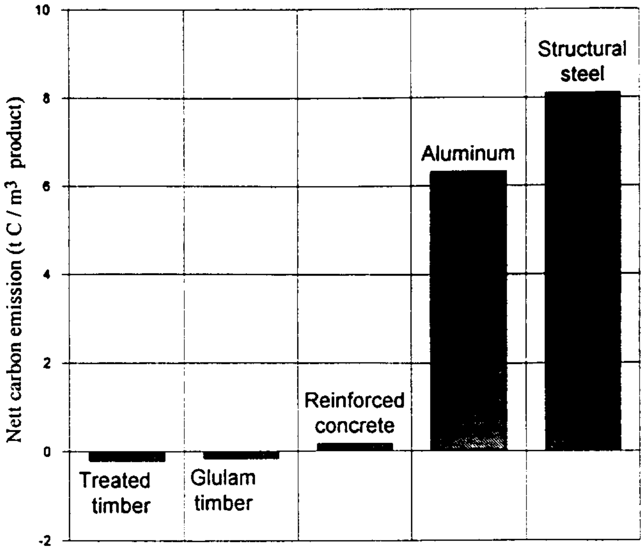

Fig. 1. Nett carbon emissions from manufacture of common building materials.

TABLE 3. Energy use and carbon emissions resulting from construction of three types of house

House type:	Maximum impact	Most common	Minimum impact
Floor	Concrete	Concrete	Timber
Exterior walls	Brick	Concrete block	Weatherboard
Roof	Corrugated galvanized steel	Corrugated galvanized steel	Concrete tiles
Framing	Steel	Timber	Timber
Windows	Aluminium	Aluminium	Wood
Energy (GJ)	520	372	218
Carbon emissions (t)	9.6	6.3	0.9

Case studies

House construction

The figures given in Appendices 1 and 2 have been used to estimate the energy requirements and resulting CO_2 emissions for house construction in New Zealand, using quantities for a typical small house (94 m^2 floor area), using several different designs. Table 3 shows the figures for a design using the most common materials, and for alternative designs which produce the minimum and maximum CO_2 emissions. Comparisons between different materials for the main components of the house are shown in Fig. 2.

For the house design using as much wood as possible, the carbon released during processing of the building materials is almost matched by that stored in the wooden components of the building.

The above figures do not include energy used for space heating, which must be included if total energy requirements of housing are to be considered. Energy requirements for space heating of houses vary

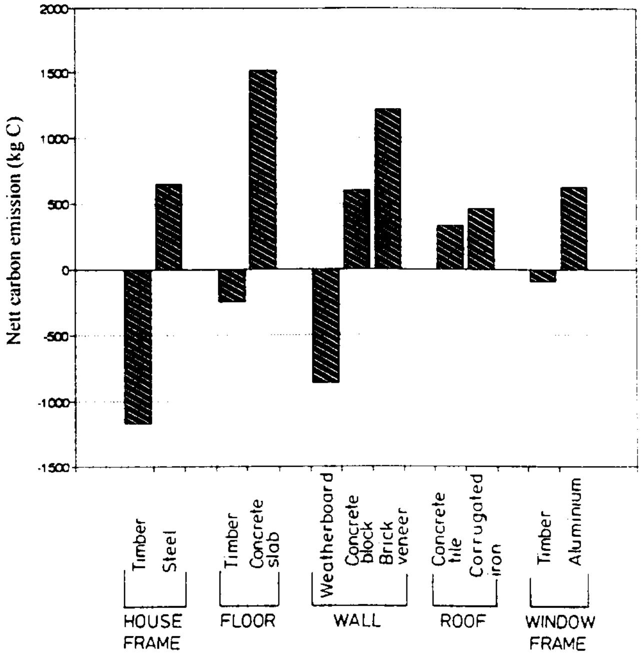

Fig. 2. Carbon emissions of main components in a typical house.

TABLE 4. Energy requirements and carbon emissions resulting from construction and heating of three types of house

House construction type	Materials (GJ)	Spacing heating requirements		25 yr total materials and heating	
		Annual (GJ/yr)	25 yrs (GJ)	(GJ)	(t,C)
Greatest energy requirement	504	32.5	812	1316	25.0
Most common	372	5.4	135	507	8.8
Smallest energy requirement	250	1.9	47	297	2.5

greatly, depending on thermal insulation, geographic location and desired levels of comfort. Common values and upper and lower extreme values have been combined with the energy to manufacture the building materials as shown in Table 4. The energy figures in Table 4 are slightly different from those in Table 3 because insulation has been removed from the maximum impact house and added to the minimum impact house to be consistent with the space heating figures. It can be seen that a combination of low impact building materials with good insulation can greatly reduce energy requirements and resulting CO_2 emissions in domestic construction.

The energy required to manufacture a house is of a similar order of magnitude to the energy required to heat the house over a 25-year life.

Industrial buildings

A typical portal frame industrial building is shown in Fig. 3. Two recent buildings of this type in Christchurch were analyzed to compare the energy requirements and CO_2 emissions of alternative designs in structural steel and glued laminated timber (glulam). A photograph of one of the glulam buildings under construction is shown in Fig. 4.

The energy and carbon emissions for both designs are shown in Table 5. The carbon emissions for the steel and timber designs are shown in Fig. 5. The left-hand columns compare the steel and timber for the structural framework alone. The right-hand columns show the totals for each building after adding the contribution from the concrete floor slab and steel cladding to walls and roof. It can be seen that the steel building has about twice the CO_2 emissions as the glulam building.

Office buildings

A similar exercise was carried out on two low-rise office structures. A recent five-storey building at the University of Canterbury (Fig. 6) is a reinforced concrete structure for which an alternative steel design was available. A similar comparison was made between reinforced concrete and glulam timber designs for a five-storey office building in Auckland [6]. The resulting figures were combined to give representative figures for multi-storey buildings in the three-to-six-storey range.

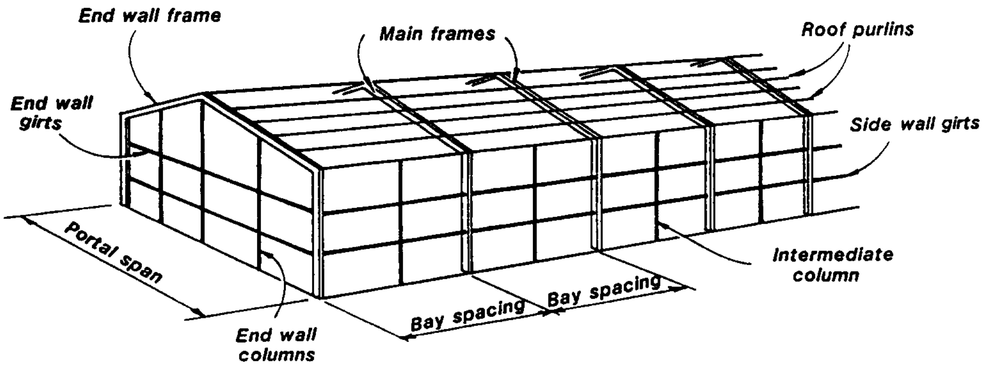

Fig. 3. Basic structure of portal frame building.

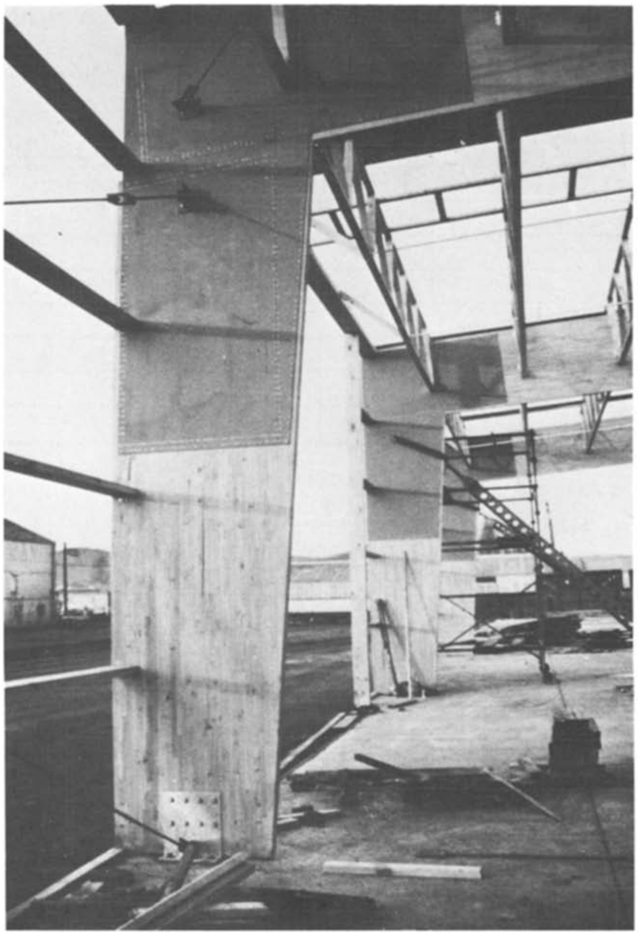

Fig. 4. Glulam portal frame industrial building with nailed steel plates at knee joint.

TABLE 5. Energy requirements and carbon emissions for construction of industrial buildings

TYPICAL INDUSTRIAL BUILDING	ENERGY	CARBON		
	GJ/m²	released kg C/m²	stored kg C/m²	nett kg C/m²
STEEL				
structural	1.6	29.2	0.0	29.1
non-structural	1.6	37.4	2.2	35.2
total	3.2	66.6	2.2	64.3
TIMBER				
structural	0.2	4.32	8.4	-4.2
non-structural	1.6	37.2	2.2	35.0
total	1.8	41.6	10.7	30.8

Table 6 shows the energy and carbon figures for office buildings constructed with reinforced concrete, steel or glulam as the main structural material. The glulam building has plywood or particle board flooring on sawn timber joists or wood I-beams. The non-structural components including roofing, linings and exterior cladding are assumed to be the

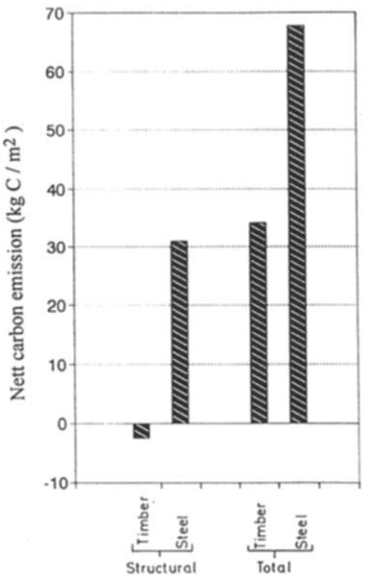

Fig. 5. Nett carbon emissions per unit floor area (kg C/m²) for portal frame buildings.

Fig. 6. Recent five-storey office building.

same for all three designs. The figures in Table 6 show that construction of a reinforced concrete building emits 90% of the CO_2 of a steel building, but the same building with a glulam frame emits only a quarter of that amount.

Hostel building

The final case study is a recently constructed YMCA hostel in Christchurch (Fig. 7). This six-storey reinforced concrete building has been re-designed in light timber framing as part of a previous project [7]. The timber design consists of plywood or particle board flooring on sawn timber joists, supported on timber stud walls with nominal 50×150 mm studs at 600 mm centres, plywood exterior cladding and gypsum plaster board linings on the walls and ceilings. Two layers of 12 mm or 16 mm gypsum board are required on most surfaces

TABLE 6. Energy requirements and carbon emissions for construction of alternative office building designs

TYPICAL HOSTEL BUILDING	ENERGY GJ/m²	CARBON released kg C/m²	CARBON stored kg C/m²	CARBON nett kg C/m²
CONCRETE				
structural	3.4	80.4	0.4	80.1
non-structural	2.2	39.5	4.5	34.9
total	5.6	119.9	4.9	115.0
STEEL				
structural	4.4	91.5	0.1	91.4
non-structural	2.2	39.5	4.5	34.9
total	6.6	131.0	4.6	126.3
TIMBER				
structural	1.5	31.7	30.8	1.0
non-structural	2.2	39.5	4.5	34.9
total	3.7	71.2	35.3	35.9

Fig. 7. Six-storey reinforced concrete hostel building.

to meet fire and acoustical requirements. Lateral loads are resisted by the walls lined with plywood and gypsum plaster board.

Table 7 shows the energy and carbon figures for the concrete and timber designs. The energy required to manufacture materials for the concrete building was 15 000 GJ which is about two days of total output from a 100 MW power station. The cost of that energy is estimated to be approximately 10% of the total cost of the building. The timber design only required two-thirds of this energy.

The difference between the two designs is much greater considering CO_2 emissions. The timber design results in less than one-third of the CO_2 emissions of the concrete design, a similar figure to the office buildings (Fig. 8).

TABLE 7. Energy requirements and carbon emissions for construction of multi-storey hostel building

TYPICAL HOSTEL BUILDING	ENERGY GJ/m²	CARBON released kg C/m²	CARBON stored kg C/m²	CARBON nett kg C/m²
CONCRETE				
structural	2.2	51.9	8.3	43.6
non-structural	1.5	28.3	1.8	26.5
total	3.7	80.2	10.1	70.1
TIMBER				
structural	1.1	23.4	29.1	-5.6
non-structural	1.5	28.5	1.8	26.7
total	2.6	52.0	30.9	21.1

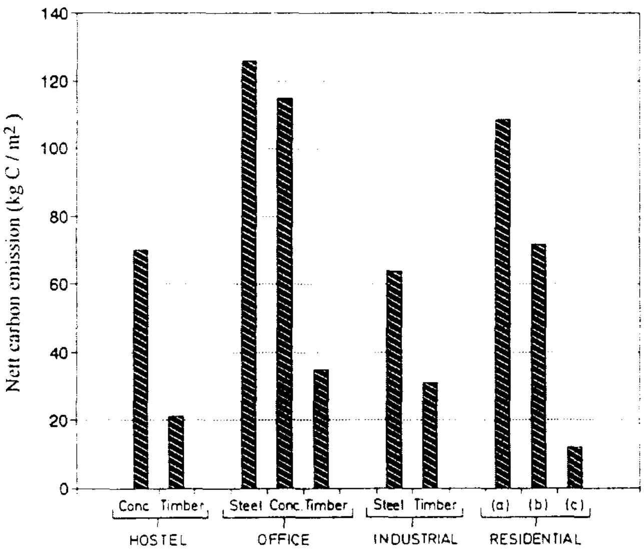

Fig. 8. Nett carbon emissions resulting from construction of buildings using different structural materials.

New Zealand totals

The production of building materials used in New Zealand buildings results in approximately 400 000 tonnes of carbon being released to the atmosphere each year as carbon dioxide, being about 6% of carbon dioxide emissions from all sources. The energy required to manufacture these materials is about 23 PJ, or 7% of New Zealand's total annual energy consumption.

With a modest change toward more timber construction in New Zealand, carbon emissions to the atmosphere could be reduced by over 100 000 tonnes, this being 25% of the emissions caused by the building industry, or 1.5% of total emissions from all sources. This does not include further reductions which would result from energy conservation and more efficient lighting, heating and cooling of buildings.

Forestry issues

The figures presented in this paper show that increased use of wood as a building material results in less energy usage and lower emissions of CO_2 to the atmosphere than other materials such as concrete or steel. These benefits of wood construction appear to contradict environmental concerns about cutting of trees and destruction of forests. The discussion below shows that there are environmental benefits from wood construction, provided that forests are managed appropriately.

Resource issues

The world uses an enormous volume of wood, about 3.5 billion tonnes per year. This annual consumption of wood is increasing steadily because the per capita consumption is remaining steady at about 0.7 tonnes per person per year, while the world's population increases by about 100 million people per year [8].

In theory, wood is a renewable resource, but in practice the world's forests are disappearing at a much faster rate than they are being replaced by natural or assisted regeneration. Destruction of tropical rainforests is particularly alarming because of the increasing rate of destruction, the irreversible loss of endangered species, the social impact on forest dwelling people, wilderness issues and soil erosion problems.

There are some regional exceptions to the global trend of forest destruction particularly in temperature coniferous forests. In New Zealand, for example, 1.2 million hectares of plantation forest provide much more wood than is required for domestic consumption and the planted area is increasing annually. Unfortunately such exceptions are almost insignificant on a global scale, as plantation forests only supply about 10% of the world's industrial wood supply.

Energy and CO_2 issues

Forest destruction results in about 2 billion tonnes of carbon entering the atmosphere as CO_2 each year [9]. Burning of fossil fuels results in the emission of another 5 billion tonnes. In New Zealand, annual carbon emissions of about 6 million tonnes are almost balanced by the carbon being absorbed by 1.2 million hectares of plantation forests.

A common reaction to concern about forest destruction is to suggest that alternatives should be found for present uses of wood. Unfortunately the alternatives have serious disadvantages, including the much larger energy demand and the greatly increased CO_2 emissions described in this paper.

Wood has the double advantage as a construction material that its production results in much lower CO_2 emissions than alternative materials, and it locks up carbon for the life of the building.

Plantation forests

The only solution to these problems is a massive increase in sustained yield forestry on a global scale. Much of this will be in planted (plantation) forests. Wood is the only major building material that is a renewable resource, but only if it is obtained from properly managed sustained yield forests.

New plantation forests absorb CO_2 from the atmosphere and store carbon as they are growing. This is beneficial while the new forests are growing, but this carbon sink cannot be a permanent solution to the greenhouse problem because sustained yield forests eventually reach a steady state where they are no longer net absorbers of carbon.

However, plantation forests are not a simple answer, because there are only finite areas of land available for planting, some of which involve conflicting environmental values, and there are limits on the capital available to make new plantings [8].

Conclusions

The global key to reducing carbon dioxide emissions to the atmosphere is the use of renewable clean energy. Until this becomes economically feasible, the short-to-medium-term response is to reduce energy use and increase energy efficiency.

The best source of renewable clean energy is solar energy, either as direct solar radiation or indirectly as hydro or wind power or using wood for fuel. Trees are able to absorb and store large quantities of solar energy.

Reinforced concrete and structural steel buildings require similar amounts of energy and result in similar levels of CO_2 emissions, both being much more than the equivalent values for wood buildings. An additional benefit of wood construction is the carbon which is 'locked up' in wood products for the life of the building.

A small but significant decrease in CO_2 emissions would result from a shift from steel, concrete and aluminium to greater use of wood in construction.

Wood is the only main building material which, sustainably managed, is a renewable resource. There is enormous potential for more use of wood, both as a fuel and as a material for many uses. This could result in greatly reduced demands for fossil fuel combustion, but will be feasible only with a massive increase in tree planting on a global scale.

Acknowledgements

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Appendix 1. New Zealand energy coefficients of building materials

No	MATERIAL/WORK	Unit	Elect	Gas	Oil	Coal	Capital	Imports	Energy Coeff. MJ/Unit	Level
1	Profits	no	0	0	0	0	0	0	0	0
2	Preliminaries	$	5.20	0.90	11.2	4.50	0.30	17.4	39.5	4
3	Administration	$	2.20	1	8.50	3.90	0	6.90	22.5	4
4	Earthwork	m^3	0	0	100	0	0	0	100	1
5	Labour	.no	0	0	0	0	0	0	0	0
6	Site.Work.(Oil)	MJ	0	0	1	0	0	0	1	1
7	Timber.Rough	m^3	232	17	378	87	14	120	848	4
7b	Timber.air-dry, treated	m^3	329	24	535	123	20	170	1200	4
7c	Timber.Glulam	m^3	1224	82	1808	449	55	883	4500	4
8	Timber.kiln-dry, treated	m^3	1280	85	1885	468	57	921	4690	4
9	Timber.Formwork	m^3	77	6	126	29	5	40	283	4
10	Hardboard	m^3	5920	379	7050	2650	531	4100	20600	4
11	Softwood	m^3	4440	284	5290	1990	400	3070	15470	4
12	Particleboard	m^3	3700	237	4408	1660	332	2560	12900	4
13	Plywood	m^3	1940	600	2360	3100	80	1360	9440	4
14	Veneer	m^3	2310	720	2800	3680	100	1610	11200	4
15	Wall.Paper	m^2	4.25	0.73	3.80	4.02	0.06	2.06	14.9	4

(*continued*)

No	MATERIAL/WORK	Unit	Elect	Gas	Oil	Coal	Capital	Imports	Energy Coeff. MJ/Unit	Level
16	Building.Paper	m^2	2.13	0.36	1.90	2.01	0.03	1.03	7.46	4
17	Cement	t	880	10	430	7340	60	260	8980	4
18	Concrete.Precast	m^3	575	69	1380	1730	89	942	4780	4
19	Concrete.Insitu	m^3	403	10	906	2180	19	321	3840	4
20	Lime.Mortar.1:2	m^3	345	7	748	1020	30	348	2500	4
21	Cement.Mortar.1:2	m^3	589	7	313	4840	40	187	5980	4
22	Structural.Clay	kg	0.53	0.01	3.30	2.23	0.38	0.44	6.90	4
23	Other.Clay	kg	25	24	41	75	2	32	199	2
24	Plaster.Solid	kg	0.81	0.33	2.61	0.33	0	2.60	6.68	2
25	Plaster.Fibrous	kg	0.81	0.33	2.61	0.33	0	2.60	6.68	2
26	Gib.board	m^3	590	170	1530	1080	0	1630	5000	2
27	Asbestos.Cement	kg	0.96	0.27	2.49	1.76	0.08	2.65	8.21	4
28	Asbestos.Others	kg	0.96	0.27	2.47	1.76	0.08	2.65	8.19	4
29	Asphalt.Felts	kg	1.10	0.70	24.70	1.90	0.10	2.60	31.1	4
30	Bitumen.Felt	kg	1.30	0.80	30.30	2.30	0.10	3.20	38.0	4
31	Glass	kg	3.51	3.56	10.70	5.04	0.32	8.37	31.5	4
32	Steel.General	kg	10.70	1.80	2.20	7.10	0.20	12.90	34.9	4
33	Steel.Rods	kg	4.74	1.19	3.56	3.56	0.21	21.68	34.9	4
34	Steel.Sections	kg	8	2	6	6	0.4	36.6	59	4
35	Galvanised.Iron	kg	3.40	1.3	3.4	3	0.2	25.6	36.9	4
36	Steel.Pipes	kg	7.70	1.9	5.8	5.8	0.4	35.3	56.9	4
37	Metals.Non-ferrous	kg	0	0	0	0	0	0	0	0
38	Aluminium.General	kg	65	0	18	8	0	39	130	2
39	Aluminium.Sheets	kg	72	0	26	8	0	39	145	2
40	Aluminium.Extrusion	kg	72	0	26	8	0	39	145	2
41	Aluminium.Foil	kg	81	0	26	8	0	39	154	2
42	Copper	kg	6.2	1.6	4.7	4.7	0.3	28.4	45.9	4
43	Zinc	kg	9.3	2.3	7	7	0.4	42.4	68.4	4
44	Lead	kg	3.4	0.9	2.6	2.6	0.1	15.6	25.2	4
45	Plastics.General	kg	18	7	16	14	1	104	160	4
46	Polyethylene	kg	2	0	2	0	0	108	112	2

(continued)

No	MATERIAL/WORK	Unit	Elect	Gas	Oil	Coal	Capital	Imports	Energy Coeff. MJ/Unit	Level
47	Polystyrene	kg	2	0	2	0	0	96	100	2
48	PVC	kg	2	0	2	0	0	92	96	2
49	Polypropylene	kg	2	0	2	0	0	171	175	2
50	Paints.General	m^2	0.52	0.2	1.51	0.51	0.09	12.07	15	4
51	Paints.Water-soluble	kg	0.31	0.1	0.75	0.26	0.04	6.04	7.5	4
52	Paints.Emulsion	m^2	0.41	0.13	1.01	0.34	0.06	8.05	10	4
53	Paints.Oil-based	m^2	0.5	0.16	1.21	0.41	0.07	9.65	12	4
54	Electrical.Work	$	5.2	0.9	11.2	4.5	0.3	17.2	39.3	4
55	Wiring	m	0.59	0.15	0.45	0.45	0.03	2.7	4.37	4
56	Electric.Equipment	$	5	1.8	5	4.1	0.4	30.5	46.8	4
57	Electric.Range	no	816	552	816	912	48	3320	6470	4
58	Aggregate	t	50	0	140	20	10	70	290	4
59	Masonry.Stone	t	50	0	140	20	10	70	290	4
60	Sand	t	10	0	20	0	0	10	40	4
61	Rubber.Synthetic	kg	13	1	18	14	2	100	148	4
62	Insulation.Fibre	kg	2.7	0.8	7	4.9	0.2	7.4	23	4
63	Fibreglass.Batts	kg	17.6	5	45.5	32	1.5	48.5	150	4
64	Brass	kg	6.7	1.7	5	5	0.3	30.5	49.2	4
65	Asphalt.Strip.Shingle	m^2	9.7	6	223	17	0.7	23.7	280	4
66	Asphalt.Surface.Rolled	m^2	2.9	1.8	67.7	5.2	0.2	7.2	85	4
67	Chip-seal.Pavement	m^2	0.2	0.22	7.98	0.02	0	0	8.42	1
68	Lime.Hydrated	kg	1.4	0.03	3.06	4.35	0.13	1.42	10.39	4
69	Quicklime	kg	1	0.02	2.18	3.10	0.09	1.01	7.4	4
70	Site.Power	MJ	1	0	0	0	0	0	1	1
71	Site.Power	$	300	0	0	0	0	0	300	1
72	Transport.Road.30km	tonne	0	0	114	0	0	0	114	1
73	Transport.Road.50km	tonne	0	0	190	0	0	0	190	1
74	Transport.Road.100km	tonne	0	0	230	0	0	0	230	1
75	Transport.Rail.200km	tonne	0	0	146	0	0	0	146	1
76	Transport.Rail.500km	tonne	0	0	365	0	0	0	365	1
77	Transport.General	$	0	0	35	0	0	0	35	1

Appendix 2. New Zealand carbon coefficients of building materials

No	MATERIAL/WORK	Unit	Energy Coeff. MJ/Unit	SCENARIO ONE		SCENARIO TWO		
				Fossil fuel energy burned MJ/Unit	Carbon released kg C/Unit	Fossil fuel energy burned MJ/Unit	Carbon released kg C/Unit	Level
1	Profits	no	0	0	0	0	0	0
2	Preliminaries	$	39.5	37.1	0.7	58.3	1.17	4
3	Administration	$	22.5	21.7	0.43	28.8	0.58	4
4	Earthwork	m^3	100	100	2	100	2	1
5	Labour	no	0	0	0	0	0	0
6	Site.Work.(Oil)	MJ	1	1	0.02	1	0.02	1
7	Timber.Rough	m^3	848	779	15.6	1400	28	4
7b	Timber.air-dry,treated	m^3	1200	1100	22	1980	39.6	4
7c	Timber.Glulam	m^3	4500	4110	82.3	7590	152	4
8	Timber.kiln-dry,treated	m^3	4692	4290	85.8	7920	158	4
9	Timber.Formwork	m^3	283	260	5.2	466	9.32	4
10	Hardboard	m^3	20600	18700	374	35800	717	4
11	Softwood	m^3	15500	14000	281	26900	538	4
12	Particleboard	m^3	12900	11700	234	22400	448	4
13	Plywood	m^3	9440	8870	177	14020	280	4
14	Veneer	m^3	11200	10500	211	16600	332	4
15	Wall.Paper	m^2	14.9	13.7	0.27	24.8	0.5	4
16	Building.Paper	m^2	7.46	6.84	0.14	12.43	0.25	4
17	Cement	t	8980	8750	311	10800	352	4
18	Concrete.Precast	m^3	4780	4600	135	6250	168	4
19	Concrete.Insitu	m^3	3840	3730	118	4730	138	4
20	Lime.Mortar.1:2	m^3	2500	2400	48	3310	66.3	4
21	Cement.Mortar.1:2	m^3	5980	5830	117	7200	144	4
22	Structural.Clay	kg	6.9	6.75	0.13	8.10	0.16	4
23	Other.Clay	kg	199	191	3.83	259	5.19	2
24	Plaster.Solid	kg	6.68	6.35	0.13	9.33	0.19	2
25	Plaster.Fibrous	kg	6.68	6.35	0.13	9.33	0.19	2
26	Gib.board	m^3	5000	4780	96	6750	135	2
27	Asbestos.Cement	kg	8.21	7.85	0.16	11.09	0.22	4

(continued)

No	MATERIAL/WORK	Unit	Energy Coeff. MJ/Unit	SCENARIO ONE Fossil fuel energy burned MJ/Unit	SCENARIO ONE Carbon released kg C/Unit	SCENARIO TWO Fossil fuel energy burned MJ/Unit	SCENARIO TWO Carbon released kg C/Unit	Level
28	Asbestos.Others	kg	8.19	7.83	0.16	11.07	0.22	4
29	Asphalt.Felts	kg	31.1	30.8	0.62	33.5	0.67	4
30	Bitumen.Felt	kg	38.0	37.6	0.75	40.9	0.82	4
31	Glass	kg	31.5	30.3	0.61	41.2	0.82	4
32	Steel.General	kg	34.9	30.6	0.61	69.16	1.38	4
33	Steel.Rods	kg	34.9	31.8	0.64	60.3	1.21	4
34	Steel.Sections	kg	59.0	53.6	1.07	102	2.04	4
35	Galvanised.Iron	kg	36.9	34.1	0.68	59.51	1.19	4
36	Steel.Pipes	kg	56.9	51.7	1.03	98.2	1.96	4
37	Metals.Non-ferrous	kg	0	0	0	0	0	0
38	Aluminium.General	kg	130	106	2.25	317	6.47	2
39	Aluminium.Sheets	kg	145	120	2.53	343	7.00	2
40	Aluminium.Extrusion	kg	145	120	2.53	343	7.00	2
41	Aluminium.Foil	kg	154	127	2.66	372	7.58	2
42	Copper	kg	45.9	41.8	0.84	79.0	1.58	4
43	Zinc	kg	68.4	62.2	1.24	118	2.36	4
44	Lead	kg	25.2	23	0.46	43.2	0.86	4
45	Plastics.General	kg	160	147	2.94	265	5.29	4
46	Polyethylene	kg	112	98	1.96	224	4.48	2
47	Polystyrene	kg	100	87	1.75	200	4.00	2
48	PVC	kg	96	84	1.68	192	3.84	2
49	Polypropylene	kg	175	153	3.06	350	7.00	2
50	Paints.General	m^2	15.0	14.2	0.28	21.6	0.43	4
51	Paints.Water-soluble	kg	7.50	7.09	0.14	10.8	0.22	4
52	Paints.Emulsion	m^2	10	9.46	0.19	14.3	0.29	4
53	Paints.Oil-based	m^2	12	11.3	0.23	17.3	0.35	4
54	Electrical.Work	$	39.3	37.0	0.74	58.1	1.16	4
55	Wiring	m	4.37	3.98	0.08	7.51	0.15	4
56	Electric.Equipment	$	46.8	43.1	0.86	76.2	1.52	4
57	Electric.Range	no	6470	6040	121	9880	198	4

(continued)

No	MATERIAL/WORK	Unit	Energy Coeff. MJ/Unit	SCENARIO ONE Fossil fuel energy burned MJ/Unit	SCENARIO ONE Carbon released kg C/Unit	SCENARIO TWO Fossil fuel energy burned MJ/Unit	SCENARIO TWO Carbon released kg C/Unit	Level
58	Aggregate	t	290	273	5.45	428	8.56	4
59	Masonry.Stone	t	290	273	5.45	428	8.56	4
60	Sand	t	40	36.7	0.73	66.7	1.33	4
61	Rubber.Synthetic	kg	148	138	2.75	232	4.63	4
62	Insulation.Fibre	kg	23	22	0.44	31.1	0.62	4
63	Fibreglass.Batts	kg	150	144	2.87	203	4.06	4
64	Brass	kg	49	44.7	0.89	85.0	1.70	4
65	Asphalt.Strip.Shingle	m^2	280	277	5.55	301	6.03	4
66	Asphalt.Surface.Rolled	m^2	85.0	84.2	1.68	91.3	1.83	4
67	Chip-seal.Pavement	m^2	8.42	8.37	0.17	8.82	0.18	1
68	Lime.Hydrated	kg	104	9.98	0.20	13.7	0.27	4
69	Quicklime	kg	7.40	7.11	0.14	9.75	0.19	4
70	Site.Power	MJ	1.00	0.75	0.02	3.00	0.06	1
71	Site.Power	$	300	225	4.50	900	18.0	1
72	Transport.Road.30km	tonne	114	114	2.28	114	2.28	1
73	Transport.Road.50km	tonne	190	190	3.80	190	3.80	1
74	Transport.Road.100km	tonne	230	230	4.60	230	4.60	1
75	Transport.Rail.200km	tonne	146	146	2.92	146	2.92	1
76	Transport.Rail.500km	tonne	365	365	7.30	365	7.30	1
77	Transport.General	$	35	35.0	0.70	35	0.70	1