STUDY REPORT

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Optimal Design of Timber Framing in Housing

J Fung and I C Page

Preface

The quantity of framing in New Zealand housing is often stated to be "excessive" compared to Australian housing. This study examines if and where timber quantities could be reduced and the cost implications of doing so. The components considered include dwangs, interior walls and junctions where timber is used for non-structural reasons. The study also examines timber floor layouts available in NZS 3604, including floors on sloping ground and the cross-over point between benched slab construction and timber pile construction.

Acknowledgments

Note

This report is intended for designers and manufacturers working in the area of timber framed construction.

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Abstract

This report examines the areas for potential saving in timber framing volumes in new housing. The components considered are studs, dwangs, top plates and internal walls. While some savings are available using the framing standard NZS 3604, the cost savings are quite small. A case is made that the reverse should apply and that designers should consider using larger sizes than 90 mm studs to improve the installation and performance of wall insulation. The project also examined various timber flooring arrangements that are feasible with NZS 3604, including costs and how they compare with concrete flooring.

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1. INTRODUCTION

This report examines the common arrangements of timber framing used in detached house building and asks whether the layouts can be refined to save on materials and costs.

Timber framing construction in Australasia and North America is based on 100 x 50 mm nominal sized sections of timber. In New Zealand the main document used for housing design is the standard NZS 3604. In recent versions of this standard the tables have been refined using rational engineering design principles. It is believed the range of member sizes and spacing provided in the standard cover the optimal range of sizes that could be used, although cost studies supporting this has not been found. This project examines the costs associated with various combinations possible from NZS 3604. It also considers potential reductions in timber used by omitting various timber members.

2. SUMMARY

The main findings are:

- Timber framing volumes can be reduced, and costs saved, by a number of measures including replacing some junction studs with steel angles, removing dwangs and reducing stud sizes for non-structural walls. The cost saving from this is approximately $28/sqm of floor area.

- However this is very much a "minimum spec" house and there are often good reasons to include more timber in a house. These include the production of a more resilient house (i.e. less vibration in use), ease of fixing appliances to walls with dwangs, and improved insulation performance. The latter occurs with the use of bigger than normal studs (e.g. 120 or 140 mm deep) and more wall insulation. The lower heating costs reduce the lifetime cost differences between "minimal" design and a better quality design.

- For timber ground floors, joist sizes of 150 or 200 mm provide cheaper sub-floor systems than layouts using 100 or 250 mm joists. A concrete slab is usually cheaper than a timber ground floor, but only up to a ground slope of about 10°. Above a 10° slope timber sub-floors become cost competitive with concrete, although the actual "threshold" slope depends on local prices and other factors such as the house layout.

3. LITERATURE SEARCH

In New Zealand a few studies on timber framing for housing have been reported in the *NZ Timber Design Journal* (Collins 1997; Chapman 1999; Ross et al 2007). Collins examined alternative timber species for framing, Chapman analysed alternative stud arrangements, and Ross looked at wide openings.

The Chapman study asked whether studs at 600 ctrs and dwangs at 800 ctrs is the most efficient arrangement. He proposed studs at 400 ctrs and no dwangs and showed that the support provided to wallboard improves, face-loading strength increases, and the amount of timber cuts and nailing is reduced. However the timber volume increases slightly by about 1%. He reported on *FRI Publication No 12 (FRI 1974),* which found that nogs added little strength to walls and that they may shrink providing reduced

resistance to stud twisting. Nogs are often used for fixing wall hangings but the FRI report found it would be more economic to place them at the required height and only as needed. They also act as thermal bridges reducing the envelope thermal performance. The FRI report concluded nogs are useful only where they support wall fixtures, and where there is a potential fire travel hazard (which nogs can block off).

In the USA the National Association of Home Builders (NAHB 1994 and 2008) published findings on optimal value engineering (OVE) of residential framing systems. The innovations they recommended included two stud exterior corners, single headers over openings, single top plates in some locations and studs at 24 inch ctrs for some walls instead of the standard 16 inch ctrs for all walls. Other savings proposed include the use of metal hangers in place of jack studs supporting lintels.

Many of these features were incorporated into the Model USA Building Code (ICC 2006). Walls in North America housing have 7/16 inch OSB sheaving and no dwangs as normal practice. This has not changed, and three stud corners, double headers with jack studs and double top plates are still the conventional practice (NAHB 2008). The reasons given for little change include:

- slow industry adoption of new practices

- problems in fixing some claddings with two stud corners

- more use of external insulation reducing the thermal bridging problem associated with 16 inch stud spacing

- problems lining up roof trusses with studs in a single top plate.

In New Zealand the standard allows for, or already has, many of what are considered to be innovations in the USA. For example, single top plates and single headers are used here. Stud spacing and sizes can be readily varied according to load cases and there is no barrier to using two stud corners if desired. Also dwangs are not mandatory. This report includes an examination of some of these less common innovations in the New Zealand context, namely reduced studs at junctions, deeper studs than the standard 100 x 50 mm stud, and removal of dwangs.

4. METHOD

NZS 3604 provides for span tables for sub-floor, walls and roof members, and various combinations were assessed for timber volumes and foundation footing volumes. The analysis included:

- Comparison of the various roof, wall and floor layouts possible in NZ 3604 and how costs vary. The aim is to identify whether any particular combination of members (i.e. piles, bearers, joists, stud sizes and spacings, rafter sizes and spacing) has significantly lower costs than other combinations.
- That most new houses are placed on a concrete slab, so costs of concrete slab construction versus timber sub-floor construction were examined for various ground slopes.
- An estimate of the quantity of "surplus" studs and dwangs used in typical construction.
- An examination of the thermal envelope effects of different wall framing arrangements.

5.   RESULTS

Most new housing is constructed on concrete slabs, and even when the ground slope is quite steep builders often prefer to use slabs with high down-slope concrete walls. This section examines the timber floor layouts possible using NZS 3604 and compares their cost to that of concrete slab floors. Potential cost savings from the use of fewer studs and dwangs are also examined.

5.1   Timber floors

As a starting point various layouts of timber floors on flat sites are considered. The aim is to demonstrate if timber volumes and costs vary significantly between the various layouts.

NZS 3604 has a number of tables giving footing sizes, and bearer and joist sizes and spans. These tables were used to assess the possible combinations of footing spacings, bearer span and joist spans, and these were examined for cost and timber volume.

Table 1 and Table 2 show various layouts for a 160 sqm single-storey house, with Wellington construction prices.

Table 1 has the bearers running along the long dimension of the plan, while Table 2 has the bearers running across the short dimension. Four different rectangular floor plans were used, ranging from long and narrow (i.e. 26.7 m long x 6 m wide) to a near square plan (i.e. 13.3 m long x 12 m wide). The layouts with the bearers running across the short dimension were generally cheaper than those with the bearers running along the house.

Table 1. NZ 3604 timber floor arrangements – bearers along long dimension

New house timber sub-floor							
160 sqm rectangular house							
Design	Width	Length	Numb. of	Joists	Bearers	Timber sub-floor	
Numb.	m	m	piles across			Vol cum	$
1	6	26.7	3	200x50ctr600 sp3	140x70sp1.3	4.38	9,187
2	6	26.7	4	150x50ctr450 sp2	140x70sp1.65	4.72	9,914
3	6	26.7	5	100x50ctr400 sp1.5	90x90sp1.3	4.51	10,995
4	8	20.0	3	250x50ctr450 sp4	140x90sp1.3	6.08	11,297
5	8	20.0	4	200x50ctr600 sp2.7	140x70sp1.3	4.44	9,670
6	8	20.0	5	150x50ctr450 sp2	140x70sp1.65	4.64	9,729
7	10	16.0	4	200x50ctr450 sp3.3	140x70sp1.3	5.05	9,852
8	10	16.0	5	150x50ctr450 sp2.5	190x70sp2	4.50	9,552
9	10	16.0	6	150x50ctr450 sp2	140x70sp1.65	4.58	10,313
10	12	13.3	4	250x50ctr450 sp4	140x90sp1.3	6.00	11,066
11	12	13.3	5	200x50ctr600 sp3	140x70sp1.3	4.29	8,846
12	12	13.3	6	150x50ctr450 sp2.4	190x70sp2	4.54	9,730
Span of member is shown after sp.							

Table 2. NZ 3604 timber floor arrangements – bearers across short dimension

New house timber sub-floor							
160 sqm rectangular house							
Design	Width	Length	Numb. of	Joists	Bearers	Timber sub-floor	
Numb.	m	m	piles across			Vol cum	$
1	6	26.7	4	150x50ctr600 sp1.8	140x90sp2	4.34	9,044
2	6	26.7	5	200x50ctr600 sp2.7	140x90sp1.65	4.54	9,226
3	6	26.7	6	250x50ctr600 sp3.8	140x90sp1.3	4.94	9,483
4	8	20.0	5	150x50ctr600 sp1.8	140x90sp2	4.35	8,965
5	8	20.0	6	150x50ctr450 sp2.5	140x90sp1.65	4.54	9,482
6	8	20.0	8	250x50ctr450 sp4	140x90sp1.3	6.02	11,086
7	10	16.0	6	150x50ctr600 sp1.8	140x90sp2	4.32	8,917
8	10	16.0	8	200x50ctr600 sp2.7	140x90sp1.65	4.56	9,291
9	10	16.0	9	250x50ctr450 sp4	140x90sp1.3	6.07	11,064
10	12	13.3	7	150x50ctr600 sp1.7	140x90sp2	4.41	9,132
11	12	13.3	9	200x50ctr600 sp2.7	140x90sp1.65	4.49	9,122
12	12	13.3	11	200x50ctr450 sp3.3	140x90sp1.3	5.25	10,282
Span of member is shown after sp.							

Figure 1 and Figure 2 are the results from Table 2 with the bearers running across the short side and the joists along the long side. The charts indicate a difference in timber volumes of up to 40% between designs. Variations in costs are less but are up are 24% between the cheapest and most expensive layouts. The designs with 250 x 50 mm joists were found to be the most expensive. The cheapest was an oblong layout, 16 x 10 m with 150 x 50 mm joists, and bearers spanning 2.0 m.

Details of the modelling are in the Appendix.
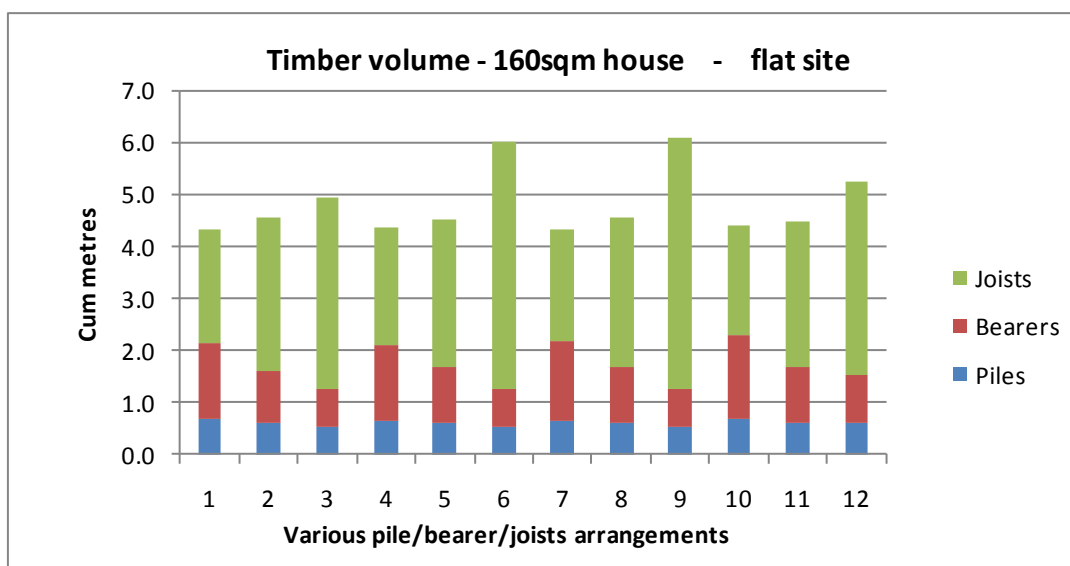
Figure 1. Timber sub-floor volumes for various NZS 3604 layouts – bearers across
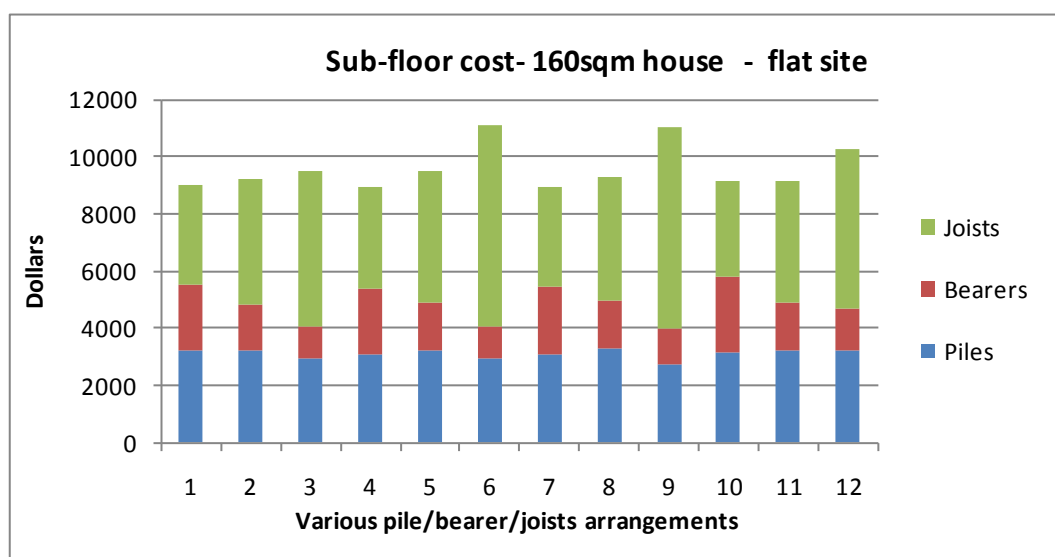
Figure 2. Timber sub-floor costs for various NZS 3604 layouts – bearers across

5.2 Timber floors on slopes

As described later, timber floors become more economic than concrete slab floors on slopes. This section looks at timber floor designs on slopes.
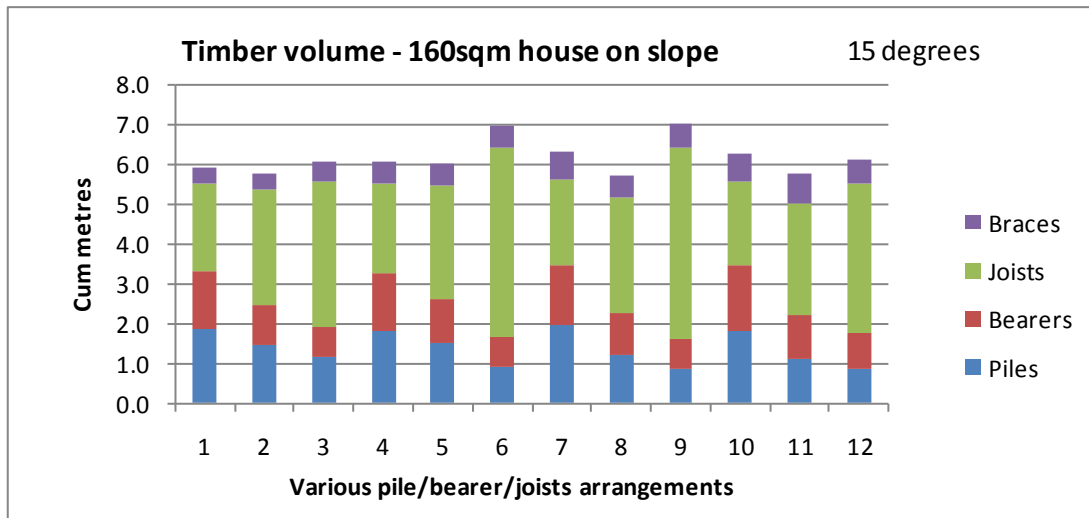
Figure 3. Timber sub-floor volumes for various NZS 3604 layouts – sloping site
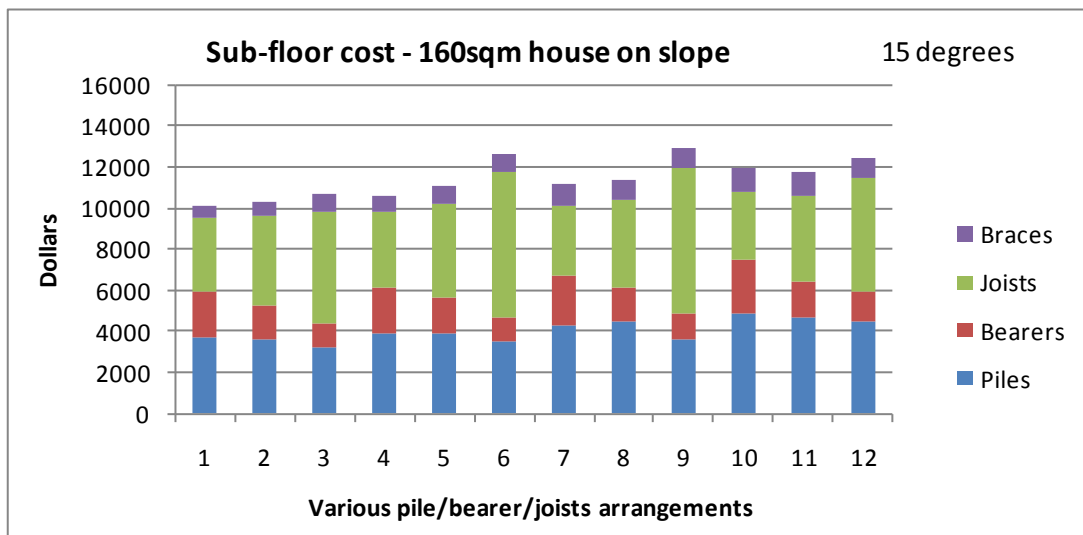
Figure 4. Timber sub-floor costs for various NZS 3604 layouts – sloping site

Figure 3 and Figure 4 have the same layouts as for the flat sites in Figure 1 and Figure 2 but now the site has a 15° slope. The bearers and joists are the same as for the flat site but the piles and braces have increased in volume and cost. Timber volumes have typically gone up by between 1-2 m^3 and costs between \$1,000 and \$2,800. This extra is due to the piles and braces required. Note that Figure 2 and Figure 4 have a similar pattern i.e. the rankings of the 12 options are similar, but not identical, in both charts.

5.3   Timber floors versus concrete floors

Most new houses have concrete floor slabs on ground, but as the ground slope increases concrete becomes more difficult to install and timber floors are more common. This section looks at the feasible arrangements and four alternatives were costed (see Figure 5):

- a timber post foundation with timber braces
- a concrete slab with a minimal benching
- a partial bench
- a full bench.

The results are shown in Figure 6 for the 160 sqm house for three selected house floor dimensions, namely 26.7 x 6 m, 20 x 8 m and 16 x 10 m. The timber floor design has the particleboard flooring cost included and underfloor insulation. These were omitted from the earlier tables because they are common to all timber designs. The reason for including them here is that the concrete options provide a finished floor, and on-ground slabs have better thermal performance than uninsulated timber floors. Flooring and insulation therefore need to be included for consistency. The timber designs also have a back retaining wall included in this section, and these are the same cost as those for the no bench concrete option because the house location on the slope is similar for both.

The results for the four options with three floor plans are shown in Figure 6. The timber floor designs are the flatter lines, and cross the concrete slab designs at between 10° and 14° slopes, i.e. for ground slopes greater than this, the timber design is cheaper than concrete. These are for simple rectangular floor plans with the smaller dimension extending down slope. At these slopes the no bench option has a downhill block wall about 1.8 m high. This accords with the general observation that in new housing areas it is not unusual to observe walls of this height backfilled to achieve a flat building platform for slab construction.

The full bench option is expensive compared to the other options above a 10° slope due to the expense of the retaining wall behind the house. At a 10° slope these walls can be over 2 m in height, depending on the clearance distance to the wall, and there are usually significant volumes of excess cut material for off-site disposal.

Details of the modelling are included in the Appendix, including material price assumptions. The cheapest solution for any particular site will depend on access and the price assumptions used here will not be applicable to all locations.

TIMBER FLOOR

NOT BENCHED

PARTIAL BENCH

FULL BENCH
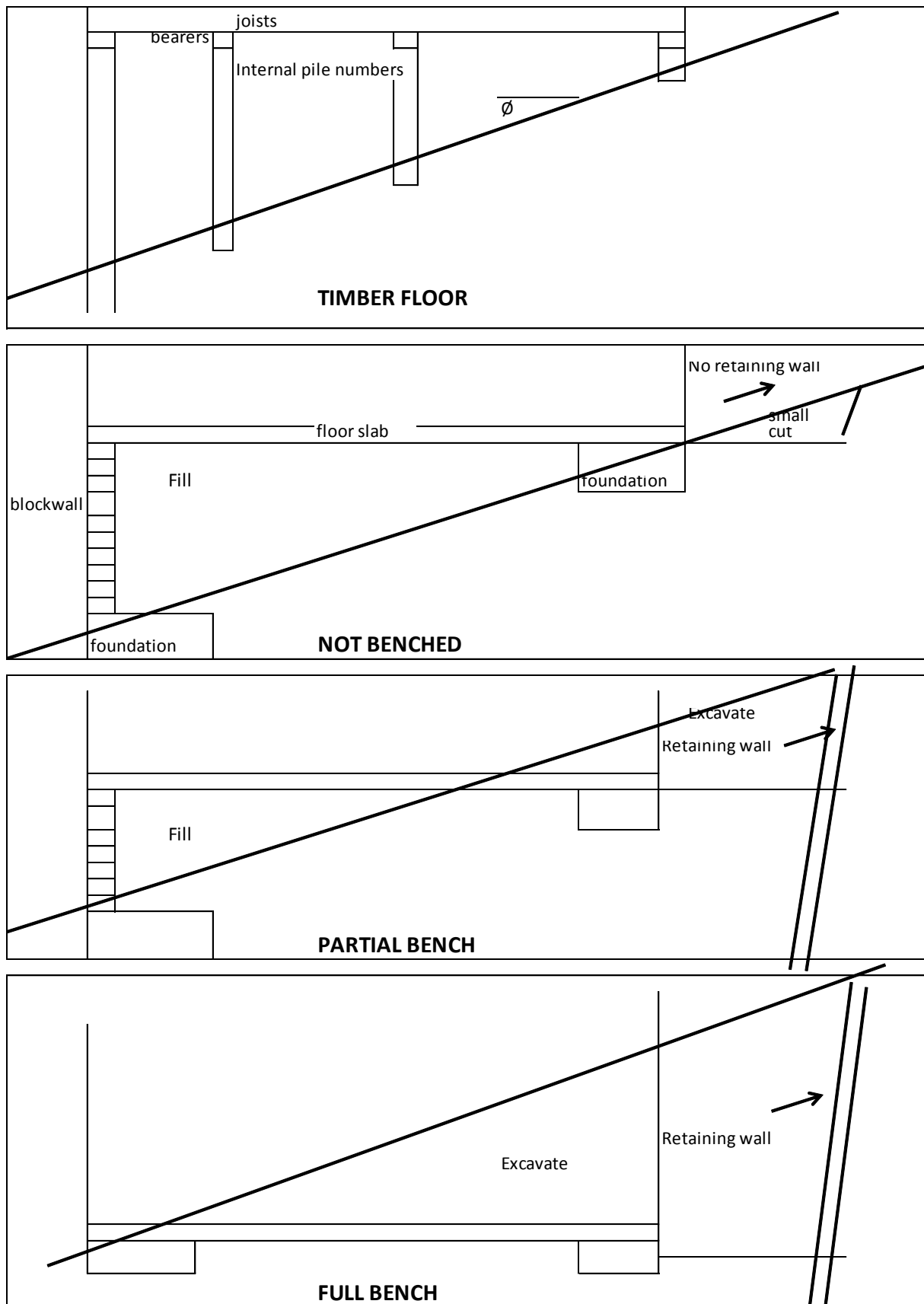
Figure 5. Concrete versus timber sub-floor alternatives
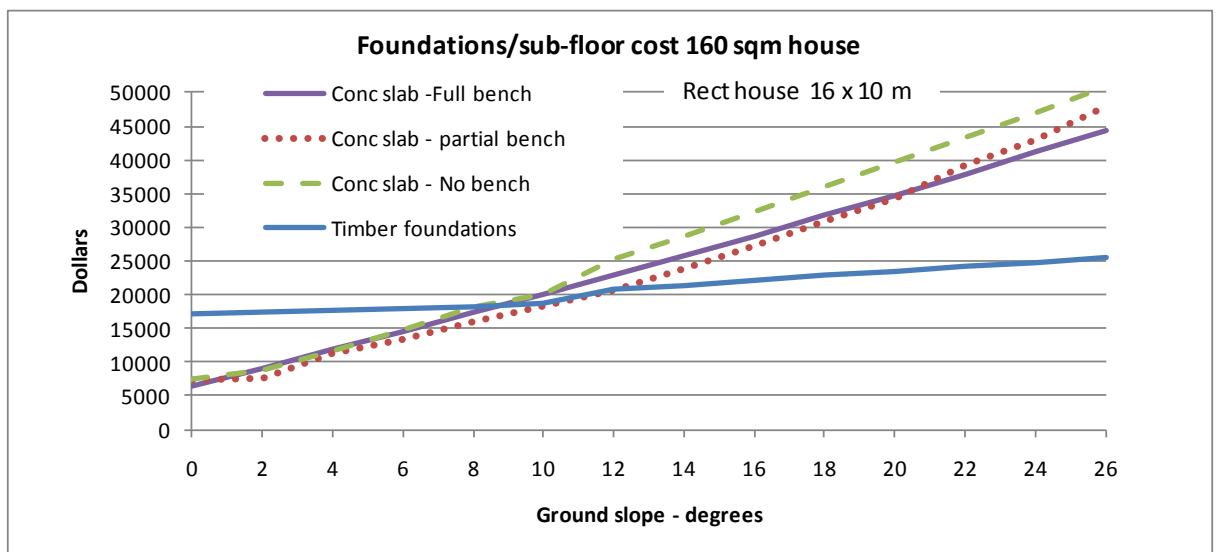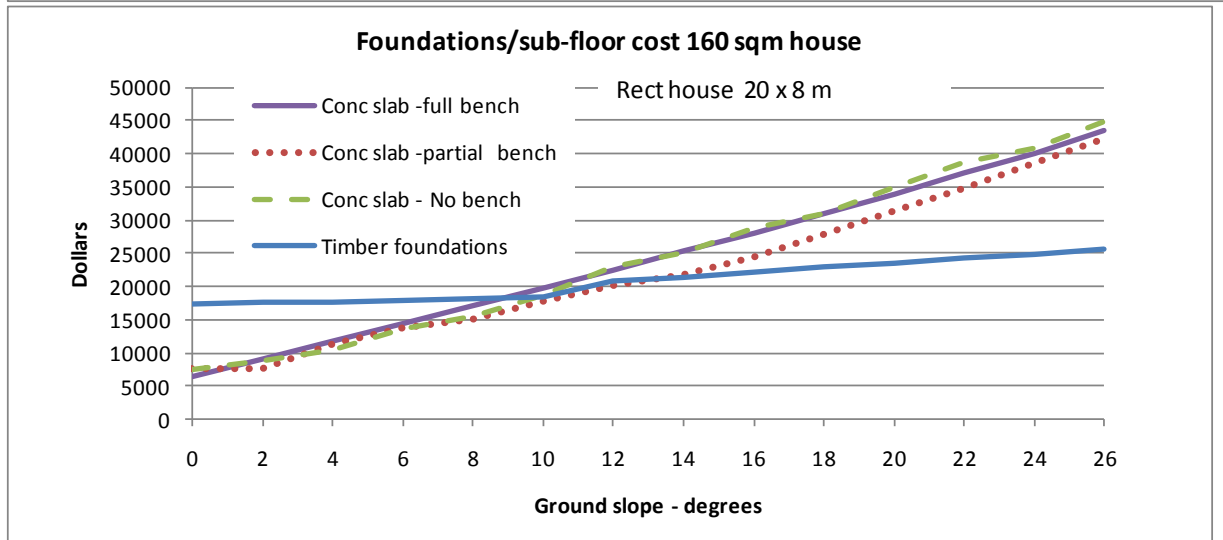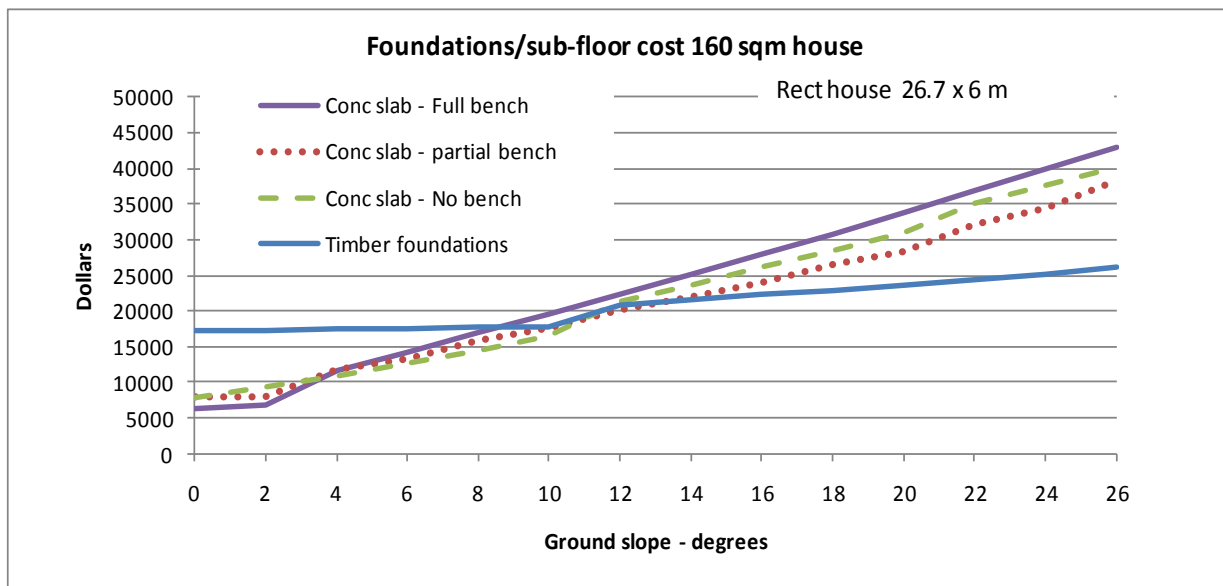
Figure 6. Timber and slab floors on slopes

5.4 Walls

The second part of this project was to examine wall framing arrangements with a view to finding potential cost savings.

The BRANZ new dwellings survey indicates that new housing has a variety of stud sizes and spacings. A sample of over 1,200 new houses indicates about 71% had 90 x 45 mm @ 600 ctrs, 19% were 90 x 45 mm at 400 or 450 ctrs, and about 6% were 140 x 45 mm studs at 600 and 400 ctrs (see Table 3). As to be expected, the incidence of other than 90 x 45 mm @ 600 ctrs was greater in two-storey construction.

Table 3. Stud sizes and spacings in new housing

Stud sizes in new housing				
For year ending December 2010.				
		Number	%	
One storey houses				
90x45@600		732	77	
90x45@400		141	15	
140x45@600		17	2	
140x45@400		18	2	
other		48	5	
		956	100	
Two storey houses				
90x45@600		171	56	
90x45@400		97	31	
140x45@600		16	5	
140x45@400		16	5	
other		8	3	
		308	100	
All houses				
90x45@600		903	71	
90x45@400		238	19	
140x45@600		33	3	
140x45@400		34	3	
other		56	4	
		1264	100	
Houses with a mix of stud sizes are counted more than once.				
Source: BRANZ New Dwellings Survey				

NZS 3604 is used for design of almost all housing and provides for a variety of wall designs, including studs, plates, lintels and trimmers. Inspection of the standard indicates that most 90 x 45 mm studs at 400 or 450 ctrs, and the 140 x 45 mm studs are likely to be in the lower storey of two-storey homes. However some single-storey houses in "high" and "very high" wind zones will require heavier/closer stud spacing, particularly if the wall height is larger than 2.4 m.

This section examines a simple single-storey house (the 1996 NZIV 1996 100 sqm modal house) and sets it in a "high" wind zone, with lightweight roof and wall claddings, and studs 90 x 45 mm @ 600 ctrs. By utilising and manipulating the floor plan and certain details of this modal house, the objectives/aims of this analysis are to investigate:

- savings using steel fixings in place of some studs, and double top plates
- alternative arrangements for studs in lower storeys.

5.4.1 Timber volume savings using steel fittings

Light steel angles are available which can be used as a substitute for some timber studs at wall junctions and a substitute for the overhanging top plate of houses with a double top plate. These replaced timbers are mainly there for fixing of linings and the steel angle can do the same job (see Figure 7). The steel angles are fixed to the stud with 30 x 2.5 mm clouts at 300 mm ctrs and 1/30 x 2.5 mm clouts to each dwang and plate. As well as reducing timber there is a potential reduction of plasterboard cracking in corners (refer to the Appendix for the details and benefits).

The amount of timber saved can be significant, and there may possibly be cost savings. These include using steel angles at wall junctions and avoiding the additional top plate when not required from strength considerations (top plate requirements are in NZS 3604, Section 8.7.1.1). Compare Case A with Case B:

- Case A: external and internal wall studs (90 x 45 mm @ 600 ctrs) and two top plates (90 x 45 mm and 140 x 35 mm).
- Case B: replace one corner stud, two "T" junction studs, and a top plate with steel angles, as shown in diagrams 1, 2 and 3 below.

1   For "L" wall junction corners: one steel angle to replace one timber stud, from three timber studs "L" wall corner to two timber studs "L" corner.
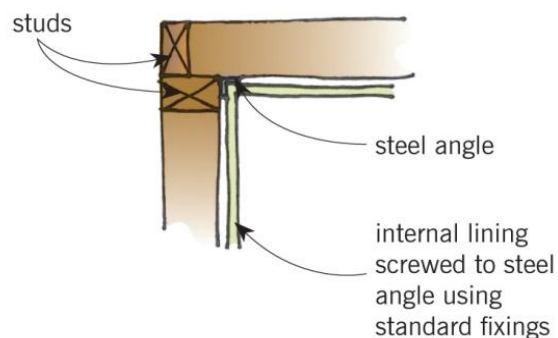
2   For "T" wall junctions: two steel angles to replace two timber studs, from three timber studs "T" wall junction to one timber stud "T" junction.
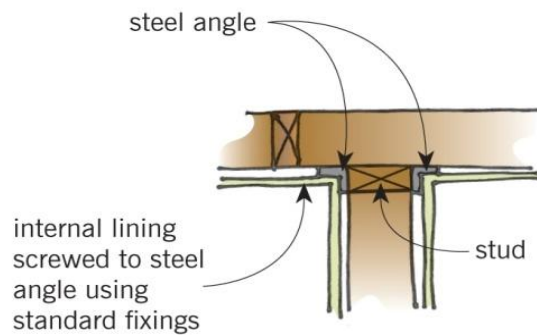
3   For the 140 x 35 mm top plate, replace with steel angles for ceiling.
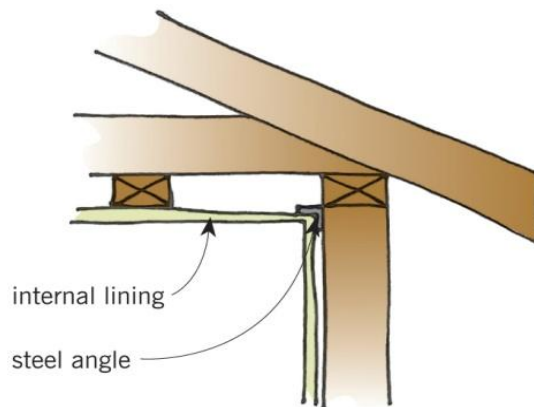
Figure 7. Steel angles used as timber member replacements

The timber volume (actual not nominal volumes) of all studs 90 x 45 mm @ 600 ctrs is 1.63 m^3, and the 140 x 35 mm top plate 0.41 m^3, totalling 2.04 m^3. The costs of these framing components range from \$4,700 to \$5,500, depending on which region the house is situated (see
Table 4).

Table 4. Timber volume and initial costs of studs and additional top plate

Timber volume			initial costs								
Case A	lin M	Timber M3		Auck		Wgtn		Chch		Dune	
Total wall studs	403	1.63	$	4,332	$	3,788	$	3,667	$	3,869	
Total wall steel angles	0	0	$	-	$	-	$	-	$	-	
Total top plate	83	0.41	$	1,162	$	975	$	1,121	$	1,038	
Total metal top plate	0	0	$	-	$	-	$	-	$	-	
Total		2.04	$	5,494	$	4,763	$	4,788	$	4,906	

The amount of timber in the 1996 NZIV house using steel angles as substitutes amounts to 1.27 m^3 and is a saving of 0.77 m^3 of timber and the initial costs saved is likely to be between $500-$900. The 1996 NZIV house had a total of 26 wall junctions, 13 "L" corners and 13 "T" junctions, accumulating to a saving of 39 studs, or 0.36 m^3. The 140 x 35 mm bottom top plate is replaced by a steel angle and accumulates to a saving of 83 linear metres, or 0.41 m^3 (see Table 5).

Table 5. Timber volumes and initial costs using steel angles and steel angle top plate as substitutes to timber

Timber volume			initial costs							
Case B	lin M	Timber M3	Auck		Wgtn		Chch		Dune	
Total wall studs	313	1.27	$	3,368	$	2,945	$	2,851	$	3,008
Total wall steel angles	90	0	$	667	$	667	$	667	$	667
Total top plate	0	0	$	-	$	-	$	-	$	-
Total metal top plate	83	0	$	617	$	617	$	617	$	617
Total		1.27	$	4,652	$	4,229	$	4,135	$	4,292

These cost savings are about $500-$800 per house, depending on the region.

All volumes are derived from the schedule of quantities of the 1996 NZIV national modal house schedule. An estimate of the number of "L" corners and "T" junctions is from the floor plan. All timber rates (around $10 per linear metre including labour and profit) are from *Rawlinsons Construction Handbook* 2009, p.204, and costs of steel angles (around $7.5 per linear metre including labour and profit) from Carters. These are located in the Appendix along with all other assumptions.

5.4.2 Studs in lower storey of two-storey houses

Studs 90 x 45 mm at 400 ctrs are the most common arrangement in the lower storey of two-storey houses in "high" wind zones. There are issues with 90 mm high-density insulation/fibreglass (R2.6) pushing linings/wraps out. One solution could be increasing the stud thickness and spacing to a 120 x 45 mm @ 600 ctrs arrangement, with and without steel angles in wall junctions and as a replacement for the additional top plate. Compare Cases 1 to 4 below, utilising the 1996 NZIV house:

- Case 1: the house has a lower storey, 100 sqm floor area, in a "high" wind zone and studs are 90 x 45 mm at 400 ctrs, with wall fibreglass insulation of R2.2.
- Case 2: as for Case 1 but remove dwangs and reduce the interior wall studs to 70 x 45 mm.
- Case 3: as for Case 1 but increase exterior studs to 120 x 45 mm @ 600 ctrs, to allow uncompressed installation of R2.6 fibreglass insulation.
- Case 4: as for Case 3 but replace some studs using steel angles in wall junctions and as a substitute for bottom top plate.

For each case we ask: "What are the timber, insulation, and energy costs in present values over 30 years? What is the total wall timber volume?" The energy costs are discounted over the analysis period of 30 years using a discount rate of 5% and the results are in Table 6 to

Table 9.

Case 1 in Table 6 is the base case. Case 2 in Table 7 has no dwangs and 70 x 45 mm internal stud walls. The comparison of Case 1 with Case 2 shows savings of about $1,500 over the 30-year analysis period. The saving is mainly in timber costs, but there is also a slight reduction in space heating costs due to slightly less thermal bridging with the removal of the dwangs.

Case 3 is similar to Case 1 except the stud size has been increased to 120 mm and R2.6 insulation is used. It has similar costs to Case 1, which is encouraging because it indicates there is little or no cost penalty in going to a deeper stud. Case 3 has the advantage of easier fitting and better performance of the insulation due to less compaction with the deeper stud. Note, however, that the increased cost of window reveals and door jambs with deeper studs has not been included. Their cost increases are likely to be small.

Case 4 is as for Case 3 but with steel angles in place of some studs. It is the cheapest of those options with dwangs and 90 mm internal walls.

The energy use differs slightly between the four options, and as expected the cooler regions use more energy than those regions to the north. Additional information is available on optimising the design of timber framing to reduce thermal bridging from organisations such as RightHouse (2009), supported by Meridian Energy.

In summary the framing standard NZS 3604 allows for the arrangement in Case 2, i.e. no dwangs and 70 x 45 mm internal walls, with a cost saving of about $1,600 per house. However, it is a less "robust" structure than the base case, as discussed later. A more useful comparison is between Cases 1 and 3 where the lifetime costs are very similar, but there is greater depth for insulation in Case 3 which ensures it is more likely to achieve its R-value than in Case 1.

Table 6. Case 1: 90 x 45 mm @ 400 ctrs, dwangs, R2.2 wall insulation

Studs 90 X 45 @400, R2.2 wall insulation							
	Initial costs and present values						
	Auck	Wgtn	Chch	Dune	**volume m3**	**area m2**	**lin M**
All wall framing timber	$ 10,776	$ 9,468	$ 9,355	$ 9,701	4.0		
Steel angles	na	na	na	na	na		
Insulation	$ 590	$ 590	$ 590	$ 590	4.4	49.2	
Energy PV over 30 years	$ 7,797	$ 16,662	$ 19,471	$ 22,381	na		
Total PV over 30 years	$ 19,163	$ 26,720	$ 29,416	$ 32,672			
one year energy kwH	2079	4443	5192	5968			

Table 7. Case 2: 90 x 45 mm @ 400 ctrs, no dwangs, R2.2 wall insulation, internal walls 70 x 45 mm

Studs 90 X 45 @400, R2.2 wall insulation. No dwangs, Interior walls 70 x 45@400						
	Initial costs					
	auck	wgtn	chch	dun	**volume m3**	
Timber	$ 9,168	$ 8,027	$ 7,981	$ 8,227	3.2	
Steel angles	na	na	na	na	na	
Insulation	$ 590	$ 590	$ 590	$ 590	4.4	49.2
Energy PV over 30 years	$ 7,748	$ 16,550	$ 19,344	$ 22,216	na	
Total PV over 30 years	$ 17,506	$ 25,167	$ 27,915	$ 31,033		
one year energy kwH	2066	4413	5158	5924		

Table 8. Case 3: 120 x 45 mm @ 600 ctrs, R2.6 wall insulation, dwangs, internal walls 90 x 45 mm

Studs 120 X 45 @600, R2.6 wall insulation							
	Initial costs and present values						
	Auck	Wgtn	Chch	Dune	**volume m3**	**area m2**	**lin M**
All wall framing timber	$ 11,338	$ 9,755	$ 10,418	$ 10,189	4.5		
Steel angles	na	na	na	na	na	na	na
Insulation	$ 726	$ 726	$ 726	$ 726	6.3	52.6	
Energy PV over 30 years	$ 7,559	$ 16,241	$ 18,959	$ 21,786	na		
Total PV over 30 years	$ 19,623	$ 26,721	$ 30,103	$ 32,701			
one year energy kwH	2016	4331	5055	5809			

Table 9. Case 4: 120 x 45 mm @ 600 ctrs, R2.6 wall insulation, dwangs, steel angles in wall junctions and bottom top plate

Studs 120 X 45 @600, R2.6wall insulation, steel angles					volume m3	area m2	lin M
	Initial costs and present values						
	Auck	Wgtn	Chch	Dune			
All wall framing timber	$ 8,953	$ 7,725	$ 8,175	$ 8,052	3.6		
Steel angles	$ 1,284	$ 1,284	$ 1,284	$ 1,284	0.01	na	173
Insulation	$ 749	$ 749	$ 749	$ 749	6.5	54.3	
Energy PV over 30 years	$ 7,486	$ 16,072	$ 18,751	$ 21,578			
Total PV over 30 years	$ 18,472	$ 25,830	$ 28,959	$ 31,664			
one year energy kwH	1996	4286	5000	5754			

5.5   Roofs

Most new houses have truss roofs because of cost and speed of erection. Their material advantage can be seen in Figure 8 where timber volumes have been estimated for both truss roofs, and rafter roofs designed using NZS 3604.

Ceiling battens, ceiling joists and roof purlins are included and a sheet steel roof is assumed. Two different section sizes/spacing arrangements were tried at each span for rafter construction, using available combinations in the NZS 3604 span tables.
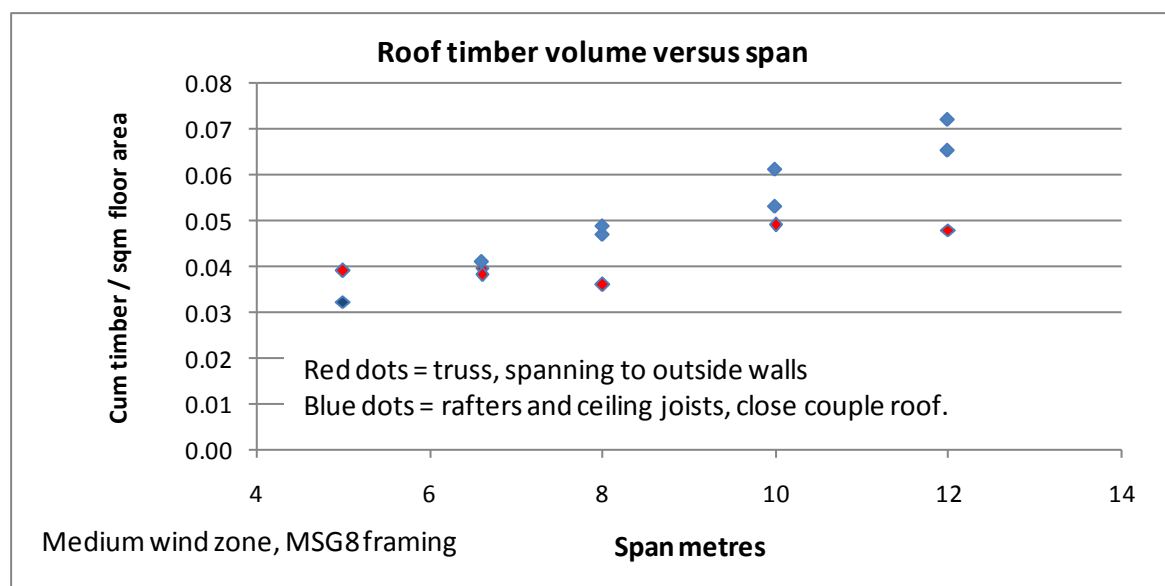
Figure 8. Roof framing timber volumes for truss and rafter roofs

At small spans the volumes for truss and rafter construction are similar, but over 6 m span the timber volume for truss construction is significantly less than for rafters. A further disadvantage for rafter construction is that the ceiling joists in NZS 3604 have a maximum span of 5.2 m, and above that rafter construction requires interior load bearing walls, whereas trusses do not.

6. DISCUSSION

The analysis of flooring systems on slopes indicates that there are good cost reasons to use concrete slab on slopes up to about $10°$, including a downhill block wall up to 1.8 m in height. On steeper slopes than $10°$ timber floors are generally cheaper. The actual cross-over point depends on house floor plan shape, local building costs, and the ease or otherwise of site access. For timber floors, joist sizes of around 150-200 mm are generally cheaper than other sizes.

Many timber studs in new housing are placed mainly to facilitate the fixing of linings. Timber volumes can be reduced by substituting some of these studs and the second top plate (if any) with metal angles. The saving has been estimated at approximately $8/sqm of floor area and this may be worthwhile where costs are critical in production of basic houses.

Further savings are possible by reducing internal wall studs from 90 to 70 mm depth. Also dwangs can be removed from walls because the wall strength is sufficient without dwangs. These changes are feasible with the framing standard NZS 3604 which provides for structural safety and serviceability (e.g. deflections of the frame in use are not excessive), but this standard is a minimum level of amenity. There are a number of issues with this minimal approach such as:

- some framing timber warps on drying and dwangs help retain the studs in shape
- lack of dwangs will cause problems in hanging wall fittings
- skimpy walls (e.g. 70 x 45 mm studs) tend to feel "flexible" and can vibrate when doors are closed.

It is suggested the focus of this research on timber frame arrangements is not so much the optimisation of the frame, as to identify the additional costs associated with providing a "quality structure".

The supposed "excess" of timber in a typical house (e.g. the widespread use of dwangs, 90 mm internal walls and "extra" studs at junctions) help provide a quality structure, which is more robust than a minimum cost design. Going further it is suggested substitution of 120 studs for the 90 mm studs more readily enables the use of R2.6 fibreglass insulation. While it can fit into 90 mm stud walls, the presence of services in the wall compresses the insulation and degrades its performance. The additional cost for a robust design with deeper studs, R2.6 insulation and retention of the "extra" studs and dwangs, is only about $28/sqm. This is believed to be a worthwhile expenditure except for the very basic level of cheap housing.

7. CONCLUSIONS

For timber floors on flat sites the more expensive options are where the joists have long spans (i.e. use of 250 x 50 mm joists). Alternatively small joists spans and many piles are also quite expensive. Joist sizes of about 150 to 200 mm appear to be the best options over all bearer spans. This assumes good foundation conditions, and if foundations were difficult then the longer joist spans would probably be more economic.

When the site is sloping a similar conclusion applies for timber floors, namely arrangements with 150 to 200 mm joists are the cheapest. On slopes, narrow long houses are cheaper than near square houses because of the increasing pile lengths with house width.

At less than 10° site slope the concrete floor options are cheaper than timber floors and the costs for concrete are similar for full or no benching into the ground slope.

There appears to be potential to reduce wall framing costs by replacing corner studs and top plates with steel angles for fixing of the lining. These cost savings are estimated at about $800 per small basic house. However for most housing retention of "extra" lining studs and dwangs, and the use of deeper studs and higher R-value insulation, provides a better quality product for an extra $28/sqm above a basic house.

8.   REFERENCES

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9. APPENDIX

This Appendix includes:

- Details of the spreadsheet models for timber and concrete floors on the flat and on the slope.
- Rafter and truss roof timber volume spreadsheet models.
- Timber, steel angle, insulation volume calculations and rates.
- Details of the thermal space conditioning analysis and assumptions.
- Details of the life-cycle cost analysis.
- Floor plan diagram and assumptions.

9.1 Floor spreadsheet models

The unit costs used in the modelling are in Table 10. The spreadsheets are shown in Table 11 to Table 14.

Table 10. Unit cost for components in house foundations

Unit costs for components, installed.		
	Cost	Unit
Timber anchor piles incl conc	107	$ ea
Ordinary timber piles 600mm incl conc	23	$ ea
125 sq H5 piles	25	$/m
Concrete footing ord/ braced for piles	30	$ ea
100 sq H5 brace timber	20	$/m
12 dia galv bolts	18	$ pair
Foundation concrte	300	$/cum
Slab concrete	290	$/cum
Block walls, grout, reinforce	130	$/sqm
Retaining timber wall incl posts	300	$/sqm
Earth cut, fill, compact	32	$/cum
Earth cut, dispose	10	$/cum
Imported basecourse fill	50	$/cum

Table 11. Timber foundations, flat site

FLAT SITE												Timber volumes cum				Timber cost $			
Trial	Width	Length	Piles	Actual	Joist	Joist	Joist	Load	Bearer	Pile spacing	Rows of								
			int	joist span		depth mm	Ctrs m	dim bearer		along m	piles #	Piles	Bearers	Joists	Total	Piles	Bearers	Joists	Total
1	6	26.7	1	3.00	200x50ctr600	200	0.6	3.00	140x70sp1.3	1.3	22	0.72	0.90	2.76	4.38	3447	1600	4140	9187
2	6	26.7	2	2.00	150x50ctr450	150	0.45	2.00	140x70sp1.65	1.65	18	0.78	1.20	2.75	4.72	3388	2133	4392	9914
3	6	26.7	3	1.50	100x50ctr400	100	0.4	1.50	90x90sp1.3	1.3	22	1.13	1.33	2.04	4.51	4586	2533	3876	10995
4	8	20.0	1	4.00	250x50ctr450	250	0.45	4.00	140x90sp1.3	1.3	17	0.58	0.90	4.60	6.08	3049	1440	6808	11297
5	8	20.0	2	2.67	150x50ctr400	150	0.4	2.67	140x90sp1.65	1.65	14	0.63	1.20	3.06	4.89	3291	1920	4896	10107
6	8	20.0	3	2.00	150x50ctr450	150	0.45	2.00	140x70sp1.65	1.65	14	0.76	1.13	2.76	4.64	3313	2000	4416	9729
7	10	16.0	2	3.33	200x50ctr450	200	0.45	3.33	140x70sp1.3	1.3	14	0.63	0.72	3.70	5.05	3022	1280	5550	9852
8	10	16.0	3	2.50	150x50ctr450	150	0.45	2.50	190x70sp2	2	9	0.52	1.20	2.78	4.50	2872	2240	4440	9552
9	10	16.0	4	2.00	150x50ctr450	150	0.45	2.00	140x70sp1.65	1.65	11	0.72	1.08	2.78	4.58	3953	1920	4440	10313
10	12	13.3	2	4.00	250x50ctr450	250	0.45	4.00	140x90sp1.3	1.3	12	0.55	0.80	4.65	6.00	2904	1280	6882	11066
11	12	13.3	3	3.00	200x50ctr600	200	0.6	3.00	140x70sp1.3	1.3	12	0.66	0.75	2.88	4.29	3192	1333	4320	8846
12	12	13.3	4	2.40	150x50ctr450	150	0.45	2.40	190x70sp2	2	8	0.55	1.20	2.79	4.54	3026	2240	4464	9730

Table 12. Concrete slab on slope, partial bench and retaining walls front and back

SLOPING SITE											SLOPE 15	degrees 0.26781		15 degrees																		
Trial	Width	Length	Piles	Downhill	Pile lengths						Braces - angle		Braces - length		Actual	Joist	Joist	Joist	Load	Bearer	Pile spac	Rows of	Timber volumes cum					Timber cost $				
			int	ht m	top	1	2	3	4	Bot	Ø Across	Ø Along	Across	Along	joist span		depth mm	Ctrs m	dim bearer		along m	piles #	Piles	Bearers	Joists	Braces	Total	Piles	Bearers	Joists	Braces	Total
1	6	26.7	1	1.61	0	0.80	0.0	0.0	0.0	1.61	75.0	39.0	3.11	3.06	3.00	200x50ctr600	200	0.6	3.00	140x70sp1	1.3	22	2.29	0.90	2.76	0.48	6.43	3938	1600	4140	796	10474
2	6	26.7	2	1.61	0	0.54	1.1	0.0	0.0	1.61	61.9	45.8	2.27	2.30	2.00	150x50ctr450	150	0.45	2.00	140x70sp1	1.65	18	2.11	1.20	2.75	0.36	6.41	3924	2133	4392	637	11086
3	6	26.7	3	1.61	0	0.40	0.8	1.2	0.0	1.61	51.2	39.0	1.92	3.06	1.50	100x50ctr400	100	0.4	1.50	90x90sp1.	1.3	22	2.84	1.33	2.04	0.39	6.61	5554	2533	3876	678	12642
4	8	20.0	1	2.14	0	1.07	0.0	0.0	0.0	2.14	75.0	31.3	4.14	3.37	4.00	250x50ctr450	250	0.45	4.00	140x90sp1	1.3	17	2.00	0.90	4.60	0.59	8.08	3735	1440	6808	931	12914
5	8	20.0	2	2.14	0	0.71	1.4	0.0	0.0	2.14	61.9	37.6	3.03	3.93	2.67	150x50ctr400	150	0.4	2.67	140x90sp1	1.65	14	1.89	1.20	3.06	0.54	6.69	4069	1920	4896	876	11761
6	8	20.0	3	2.14	0	0.54	1.1	1.6	0.0	2.14	51.2	37.6	2.57	3.93	2.00	150x50ctr450	150	0.45	2.00	140x70sp1	1.65	14	2.12	1.13	2.76	0.51	6.52	4294	2000	4416	830	11540
7	10	16.0	2	2.68	0	0.89	1.8	0.0	0.0	2.68	61.9	25.9	3.78	3.73	3.33	200x50ctr450	200	0.45	3.33	140x70sp1	1.3	14	2.12	0.72	3.70	0.59	7.13	4146	1280	5550	931	11908
8	10	16.0	3	2.68	0	0.67	1.3	2.0	0.0	2.68	51.2	36.8	3.21	4.81	2.50	150x50ctr450	150	0.45	2.50	190x70sp2	2	9	1.57	1.20	2.78	0.63	6.17	3765	2240	4440	982	11427
9	10	16.0	4	2.68	0	0.54	1.1	1.6	2.1	2.68	43.1	31.7	4.54	4.25	2.00	150x50ctr450	150	0.45	2.00	140x70sp1	1.65	11	2.14	1.08	2.78	0.69	6.68	5373	1920	4440	1059	12792
10	12	13.3	2	3.21	0	1.07	2.1	0.0	0.0	3.21	61.9	22.0	4.54	4.13	4.00	250x50ctr450	250	0.45	4.00	140x90sp1	1.3	12	2.03	0.80	4.65	0.68	8.16	4178	1280	6882	1047	13387
11	12	13.3	3	3.21	0	0.80	1.6	2.4	0.0	3.21	51.2	22.0	3.85	4.13	3.00	200x50ctr600	200	0.6	3.00	140x70sp1	1.3	12	2.33	0.75	2.88	0.62	6.58	4818	1333	4320	978	11450
12	12	13.3	4	3.21	0	0.64	1.3	1.9	2.6	3.21	43.1	31.9	5.45	5.13	2.40	150x50ctr450	150	0.45	2.40	190x70sp2	2	8	1.77	1.20	2.79	0.83	6.59	4316	2240	4464	1238	12258

Table 13. Concrete slab on slope, minimal bench, no retaining wall at back

SLOPING SITE	CONCRETE FOUNDATION				SLOPE =	15	degrees	0.26781			Costs							
	NO RETAINING WALL AT BACK - MINIMAL BENCH																	
Trial	Width	Length			Downhill	Blocks	Fdns	Masonry	Ord fill	Hardfill	cut	slab		Fdns	Block	Cut to	Hardfill	Cut to		Slab	Total
					ht m	rows	Volm3	blks sqm	volm3	volm3	volm3	Volm3			walls	fill		dispose			$
1	6	26.7			1.61	9	7.89	58.8	122	14.7		16.0		2368	7644	3900	735	0		4640	19288
2	6	26.7			1.61	9	7.89	58.8	122	14.7		16.0		2368	7644	3900	735			4640	19288
3	6	26.7			1.61	9	7.89	58.8	122	14.7		16.0		2368	7644	3900	735			4640	19288
4	8	20.0			2.14	11	8.50	61.6	153	14.9		16.0		2550	8008	4892	745			4640	20835
5	8	20.0			2.14	11	8.50	61.6	153	14.9		16.0		2550	8008	4892	745			4640	20835
6	8	20.0			2.14	11	8.50	61.6	153	14.9		16.0		2550	8008	4892	745			4640	20835
7	10	16.0			2.68	14	9.50	72.8	199	15.0		16.0		2851	9464	6360	749			4640	24064
8	10	16.0			2.68	14	9.50	72.8	199	15.0		16.0		2851	9464	6360	749			4640	24064
9	10	16.0			2.68	14	9.50	72.8	199	15.0		16.0		2851	9464	6360	749			4640	24064
10	12	13.3			3.21	17	10.84	86.1	244	15.0		16.0		3253	11197	7814	750			4640	27654
11	12	13.3			3.21	17	10.84	86.1	244	15.0		16.0		3253	11197	7814	750			4640	27654
12	12	13.3			3.21	17	10.84	86.1	244	15.0		16.0		3253	11197	7814	750			4640	27654

Table 14. Concrete slab on slope, full bench, retaining wall at back

SLOPING SITE	CONCRETE FOUNDATION				SLOPE =	15	degrees	0.26781			Costs			Clearance at back of house				1.5	m
	RETAINING WALL AT BACK - FULL BENCH																		
Trial	Width	Length			Uphill		Fdns			Hardfill	cut	slab		Fdns	Block	Cut to	Hardfill	Cut to	Timber	Slab	Total
					ht m		Volm3			volm3	volm3	Volm3			walls	fill		dispose	wall		$
1	6	26.7			2.01		1.93			14.7	223.5	16.0		580	0	0	735	2235	17876	4640	26066
2	6	26.7			2.01		1.93			14.7	223.5	16.0		580	0	0	735	2235	17876	4640	26066
3	6	26.7			2.01		1.93			14.7	223.5	16.0		580	0	0	735	2235	17876	4640	26066
4	8	20.0			2.54		1.80			14.9	278.0	16.0		540	0	0	745	2780	17555	4640	26259
5	8	20.0			2.54		1.80			14.9	278.0	16.0		540	0	0	745	2780	17555	4640	26259
6	8	20.0			2.54		1.80			14.9	278.0	16.0		540	0	0	745	2780	17555	4640	26259
7	10	16.0			3.08		1.80			15.0	336.5	16.0		540	0	0	749	3365	17555	4640	26848
8	10	16.0			3.08		1.80			15.0	336.5	16.0		540	0	0	749	3365	17555	4640	26848
9	10	16.0			3.08		1.80			15.0	336.5	16.0		540	0	0	749	3365	17555	4640	26848
10	12	13.3			3.62		1.87			15.0	398.6	16.0		560	0	0	750	3986	17715	4640	27652
11	12	13.3			3.62		1.87			15.0	398.6	16.0		560	0	0	750	3986	17715	4640	27652
12	12	13.3			3.62		1.87			15.0	398.6	16.0		560	0	0	750	3986	17715	4640	27652

9.2 Roof options

Table 15. Rafter construction timber volumes from NZS 3604

Bldg width m	with eaves	Rafter span m no eaves	eaves	Rafter size	spacing	Ceiling joist size	spacing	Roof purlin size	end span 0.2W	Number of purlins at ends	interm	tot	Timber volumes cum Rafters	C joist	Purlins	Ceiling battens	Total cum	Cum per sqm
5	6.2	2.70	3.34	140x45	1.2	90x45	0.48	90x45	1.24	12	0	12	0.70	0.78	0.87	0	2.35	0.032
6.6	7.8	3.56	4.21	140x45	0.6	140x45	0.6	70x45	1.56	16	0	16	1.64	1.24	0.87	0	3.75	0.039
6.6	7.8	3.56	4.21	190x45	0.9	140x35	0.48	70x45	1.56	16	0	16	1.51	1.23	0.87	0	3.61	0.038
8	9.2	4.31	4.96	190x45	0.6	190x45	0.9	70x45	1.84	16	0	16	2.58	1.36	0.87	0.65	5.46	0.047
8	9.2	4.31	4.96	290x45	0.9	190x45	0.9	70x45	1.84	16	0	16	2.68	1.36	0.87	0.65	5.56	0.048
10	11.2	5.39	6.04	190x70	0.6	190x45	0.48	70x45	2.24	20	0	20	4.71	3.10	1.09	0	8.90	0.061
10	11.2	5.39	6.04	240x70	1.2	190x45	0.48	90x45	2.24	20	0	20	3.17	3.10	1.45	0	7.72	0.053
12	13.2	6.47	7.12	290x70	0.9	190x45	0.4	70x45	2.64	20	2	22	5.77	4.44	1.20	0	11.40	0.066
12	13.2	6.47	7.12	240x70	0.6	190x45	0.4	70x45	2.64	20	2	22	6.94	4.44	1.20	0	12.58	0.072
						assumes one												
Assume 14.5 M long gable construction.						int load wall.			22 deg roof slope						Ceiling battens = 70x35			

Table 16. Truss timber volumes

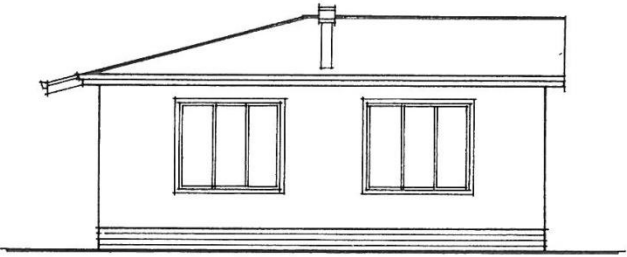| Bldg width m	Top chord m	Bottom chord m	chords	webs	spacing	Web lengths m end	mid	Total Vol/truss cum chords	webs	Total	Number	Vol cum	purlins	vol cum	Ceiling battens cum	Total cum	Cum per sqm
5	6.69	5	140x45	90x45	1.2	0.62	1.49	0.088	0.021	0.1087	14	1.52	90x45	0.87	0.44	2.83	0.039
6.6	8.41	6.6	140x45	90x45	1.2	0.82	1.96	0.113	0.028	0.140	14	1.97	90x45	1.16	0.52	3.65	0.038
8	9.92	8	140x45	90x45	1.2	1.00	2.38	0.134	0.034	0.1682	14	2.35	90x45	1.16	0.65	4.17	0.036
10	12.08	10	190 x 45	140x45	0.9	1.01	2.70	0.221	0.071	0.2915	18	5.25	70x45	1.09	0.78	7.12	0.049
12	14.24	12	190 x 45	140x45	0.9	1.21	3.24	0.262	0.085	0.3472	18	6.25	70x45	1.20	0.91	8.36	0.048
Assume 14.5 M long gable construction.									22 deg roof slope						Ceiling battens = 70x35		

9.3   Appendix: Wall framing details, estimates, assumptions

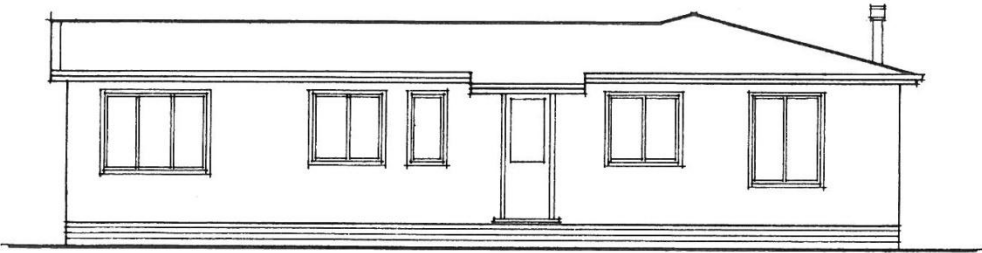### 9.3.1 1996 NZIV floor plan and wall framing details – 100 sqm
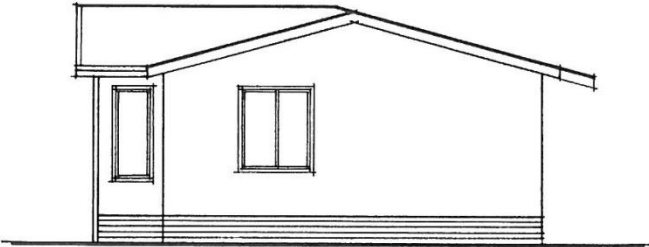

FLOOR PLAN SCALE 1:100

LEGEND
1 - entry
2 - living
3 - dining
4 - kitchen
5 - laundry
6 - toilet
7 - bathroom
8 - hall
9 - bedroom
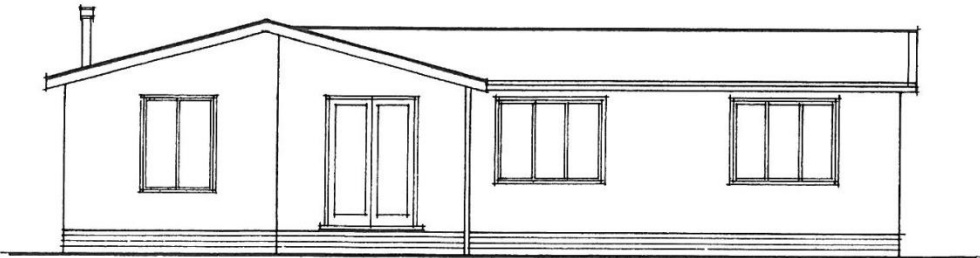10 - bedroom
11 - bedroom
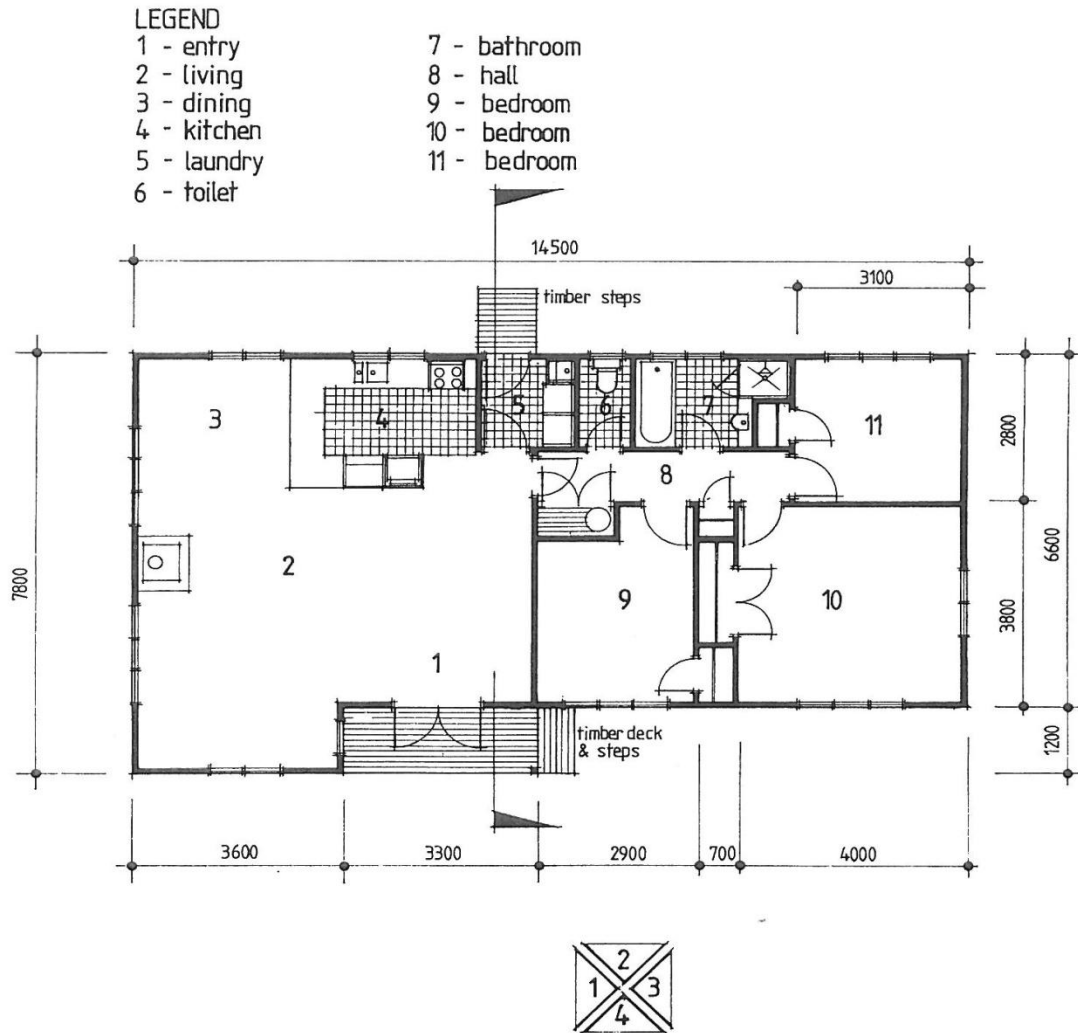
ELEVATION 1 SCALE 1:100

ELEVATION 2 SCALE 1:100

ELEVATION 3 SCALE 1:100

ELEVATION 4 SCALE 1:100

9.3.2 Number of wall corners and junctions

Total "L" corners = 13 (1 x 13 = 13 studs in these corners can be replaced by metal angles)

Total "T" junctions = 13 (2 x 13 = 26 studs in these intersection walls can be replaced by metal angles)

Total studs suitable to be replaced with steel angles = 39.

9.3.3 1996 NZIV wall framing schedule of quantities

Schedule of quantities: Wall framing (Studs 90mm X 45mm @ 600 centres)				
External wall	thick (mm)	width (mm)	lin M	Volume M3
studs	45	90	205	0.83
dwangs	45	90	134	0.54
top plate 1	45	90	45	0.18
top plate 2 (additional)	35	140	45	0.22
bottom plate	45	90	43	0.17
sill trimmer	45	90	16	0.06
lintel	115	90	8	0.08
lintel	90	90	2	0.02
vol m3				2.11
Internal wall				
studs	45	90	198	0.80
top plate 1	45	90	38	0.15
top plate 2 (additional)	35	140	38	0.19
bottom plate	45	90	29	0.12
lintel	115	90	3	0.03
lintel	90	90	7	0.06
vol m3				1.35
Total wall framing m3				3.46

From the schedule of quantities, the total volume for studs is 1.63 m^3, and the second top plate is 0.41 m^3.

9.3.4 Volumes, areas, linear metrics for timber, steel angle and insulation

The four houses with NZIV floor plan as a lower storey, analysed, are:

1. Case 1: 90 x 45 mm @ 400 ctrs, dwangs and R2.2 wall insulation.

2. Case 2: 90 x 45 mm @ 400 ctrs, no dwangs, 70 x 45 mm internal walls, and R2.2 wall insulation.

3. Case 3: 120 x 45 mm @ 600 ctrs, dwangs, R2.6 wall.

4. Case 4: 120 x 45 mm @ 600 ctrs, dwangs, steel angles replacing junction studs and second top plate.

The amount of insulation was estimated by mapping out the wall framing design for each exterior wall. Wall insulation area is the net wall area that is non-timber, excluding openings.

Note: As the 1996 NZIV house has studs at 600 ctrs, the Case 1 timber volume is obtained by estimating the amount of studs for a 90 x 45 mm @ 400 ctrs arrangement plus all other timber components. A comparison for the accuracy of this estimate is verified by mapping estimates of the stud arrangement for studs at the initial 600 ctrs spans. By mapping/drawing out 600 ctrs, the total amount of external wall studs equalled 208 linear metres compared with the actual 205 linear metres on 1996 NZIV schedule, p.32. Hence, the method for calculating timber volumes for Case 1 at 400 ctrs is believed to be an accurate estimate.

Case 1: 90 x 45 mm @ 400, dwangs, R2.2 wall insulation, 90 x 45 mm internal walls

1. The schedule of quantities for timber is for a 90 x 45 mm @ 600 ctrs arrangement. The only change to timber volumes for this arrangement is obtained by estimating the amount of studs for 90 x 45 mm @ 400 ctrs. By mapping/drawing each exterior and interior wall (using the 1996 NZIV house with studs at 400 ctrs), the total amount of external wall studs equalled 284 linear metres ($1.2 \ m^3$), and internal studs equalled 258 linear metres ($1.0 \ m^3$).

2. Insulation is 49.2 sqm for the 90 mm wall, or 4.4 m^3.

Case 2: 90 x 45 mm @ 400, no dwangs, R2.6 wall insulation, internal walls 70 x 45 mm @ 600 ctrs

The dwangs volume is taken off the NZIV schedule, and the internal wall studs volume adjusted for 70 mm instead of 90 mm thickness.

Case 3: 120 x 45 mm @ 600, dwangs, R2.6 wall insulation, 90 x 45 mm @ 600 ctrs internal walls

Timber volume is obtained by changing the stud depth from 90-120 mm using the NZIV schedule. This amount for all studs is 403 linear metres, or 2.2 m^3

1. Insulation is 52.6 sqm for the 120 mm wall, or 6.3 m^3.

Case 4: 120 x 45 mm @ 600 ctrs, R2.6 wall insulation, 90 x 45 mm internal walls, and with steel angles in wall junctions and bottom top plate

1. Timber volume is obtained using Case 3 and replacing the corner and junction studs, and one top plate with metal angles (refer to 5.4.1.) This amount for all studs is 301 linear metres, or 1.7 m^3 of timber.

2. Insulation is 54.3 sqm for the 120 mm wall, or 6.5 m^3.

3. Steel angles amount to a total of 39 replaceable studs and 81 linear metres of bottom top plate from the NZIV schedule. The total steel angle length is 173 linear metres.

9.3.5 Costs, rates, timber, steel angle, insulation and energy

All rates are GST exclusive.

9.3.5.1 Timber rates

Timber rates are from *Rawlinsons Construction Handbook 2009*.

120 mm timber is estimated as the average linear metre rate of 90 mm and 140 mm framing.

The framing component timber is the timber component rate multiplied by the linear metre for that component.

Timber rates, framing grade MSG8								
	dimension	Auck	Wgtn	Chch	Dune		Reference	
		Dollars per linear metre			$/lin M			
studs 90 x 45	90 x 45	$ 10.8	$ 9.4	$ 9.1	$ 9.6		Rawlinsons p202	
	120 x 45	$ 13.2	$ 11.3	$ 12.1	$ 11.8		BRANZ est from Rawlinson's rates p 202	
dwangs	90 x 45	$ 12.0	$ 10.8	$ 10.3	$ 11.0		Rawlinsons p202	
	120 x 45	$ 14.4	$ 12.6	$ 13.2	$ 13.2		BRANZ est from Rawlinson's rates p 202	
top plate 1	90 x 45	$ 9.6	$ 8.7	$ 8.5	$ 8.8		Rawlinsons p202	
	120 x 45	$ 13.2	$ 11.3	$ 12.1	$ 11.8		BRANZ est from Rawlinson's rates p 202	
top plate 2, bottom TP	140 x 35	$ 14.0	$ 11.8	$ 13.5	$ 12.5		BRANZ est from Rawlinson's rates p 202	
bottom plate	90 x 45	$ 9.6	$ 8.7	$ 8.5	$ 8.8		Rawlinsons p202	
	120 x 45	$ 13.2	$ 11.3	$ 12.1	$ 11.8		BRANZ est from Rawlinson's rates p 202	
sill trimmer	90 x 45	$ 10.8	$ 9.3	$ 9.0	$ 9.5		Rawlinsons p202	
	120 x 45	$ 13.2	$ 11.2	$ 12.0	$ 11.7		BRANZ est from Rawlinson's rates p 202	
lintel 1	90 x 115	$ 26.3	$ 22.9	$ 24.1	$ 23.6		BRANZ est from Rawlinson's rates p 202	
	120 x 115	$ 35.0	$ 30.5	$ 32.2	$ 31.5		BRANZ est from Rawlinson's rates p 202	
lintel 2	90 x 90	$ 21.3	$ 18.8	$ 18.0	$ 19.0		Rawlinsons p202	
	120 x 90	$ 28.3	$ 25.0	$ 24.0	$ 25.3		BRANZ est from Rawlinson's rates p 202	

9.3.5.2 Steel angles

The advantages of steel angles include:

- they eliminate studs and blocks at wall junctions and corners
- they can adjust for an uneven floor so the ceiling is level.

The disadvantages of steel angles include:

- the time to fix
- getting a straight alignment for the ceiling edge.

Rates for these steel angles are not in *Rawlinsons 2009*, so BRANZ estimated a rate for these to be $7.40 per linear metre from the following:

1. $12.60 including GST per 2.4 m steel angles from Carters.
2. Builder's rate of $50 per hour including overheads and profit.
3. Five minutes to fix 13 clouts per wall steel angle to timber (costs of clouts are $5 per 100 clouts).
4. These rates are applied for all regions.

Total cost for steel angles is the rate multiplied by the steel linear metre required.

9.3.5.3 Insulation

Insulation types used are:

1. R2.2 90 mm wall insulation, $11/sqm from *Rawlinsons 2009*.
2. R2.6 90mm insulation, $16/sqm from *Rawlinsons 2009.*

These rates are applied for all regions. Total cost for insulation is the rate multiplied by the insulation sqm required in wall framing

9.3.5.4 Energy costs

Energy rates are assumed to be an average of 20 cents per kilowatt hour (kWh) for all regions. Total energy costs are the annual kWh x rate per kWh.

9.3.6 Thermal modelling

The heating energy use was modelling using ALF 3.2 software. The parameters were:

- 100 sqm house, whole house heating at 20° for morning and evening (7am to 9am, 5pm to 11pm)
- four locations were used: Auckland, Wellington, Christchurch and Dunedin.

The options compared were:

1. Case 1: 90 x 45 mm studs @ 400 ctrs, two rows of dwangs, bevel-back weatherboard, use R2.2 insulation.

2. Case 2: as for Case 1 but thermal bridging is reduced slightly with no dwangs giving savings of between 15kWh/yr and 40kWh/yr, depending on the region.

3. Case 3: 120 x 45 mm studs @ 600 ctrs, two rows of dwangs, bevel-back weatherboard, use R2.6 insulation.

4. Case 4: 120 x 45 mm studs @ 600 ctrs, two rows of dwangs, with steel angles, use R2.6 insulation. Thermal bridging is reduced slightly compared to Case 3 due to fewer studs.

ALF does not have a 120 x 45 mm option, so the energy kWh per year for a house with the arrangement 120 x 45 mm @ 600 is estimated to be the average of a house with studs 90 x 45 mm @ 600 ctrs and a house with studs 140 x 45 mm @ 600 ctrs.

The use of steel angle studs reduced the thermal bridging area by about 15% which is a similar change going from 600 to 400 stud spacing. Hence the same reduction from ALF in kWh for 400-600 mm stud ctrs was used for replacement of some timber studs with steel angles.

9.3.7 Present value: initial costs and life-cycle cost analysis for heating energy

The analysis was the net present value analysis. The house with the lowest overall present value is most cost-effective.

Total PV = initial cost, i.e. timber + insulation + steel angles (if applicable) + energy PV

Where energy PV = energy costs over year multiplied by: [(1+e) x ((1+d)t – (1+e)t)] / [(d-e) x (1+d)t]

Where:
Assume an energy price of $0.20 per kWh:
e = energy price escalation = 1.6% pa above the general inflation rate
r = real discount rate = 5%
t = time from one year out to 30 years and ∑ is the sum over 30 years.