Optimum Specification for New Zealand Houses

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Abstract

At present New Zealand is divided into three climate zones in terms of the Energy Efficiency Building Code requirements. Light timber framed construction type and the 'mass construction type' commonly used in the Auckland region do not satisfy the requirements for the colder climate region. In order to determine the total impact a particular building makes on the environment, operating as well as construction requirements over the useful life of such buildings should be considered. However, since buildings last for a long period compared to building materials and equipment – around 100 years – the data required for an analysis of life cycle energy and cost are numerous and analysis would be tedious and time consuming and often not practical for a practicing architect. This paper describes a method that has been developed at the University of Auckland for a detailed life cycle analysis of an individual house based on the embodied and operating energy requirements and life cycle cost over the useful life of the building with funding from the Public Good Science Fund of the Foundation for Research, Science and Technology of New Zealand. This design tool allows a building to be assessed at the design stage, so that various design options and strategies can be compared with one another and also to quantify the environmental impact of New Zealand house designs over their useful lifetime. Although the model is based on the generic construction types that are currently being used, it has been designed as an expert system so that updating the model database can be done with relative ease. The rest of the paper discusses the use of this tool to explore the optimum specification for house construction for the different climate regions of New Zealand in terms of life cycle energy and cost.

1. INTRODUCTION

Buildings and their services, while providing the occupants with a comfortable internal environment, affect the external environment. While this impact could affect the performance and the viability of the buildings, the magnitude of the environmental impact depends on the decisions taken over the entire life of the building. Buildings have a long life and continue to provide their services over long periods, during which energy is expended and costs are incurred to maintain and operate them at a habitable level. As such if the impact a particular building makes on the environment is to be determined, a method that considers construction, maintenance as well as operating requirements of various buildings, over the total useful life of such buildings is required. However, as buildings last for a long period compared to building materials and equipment – around 100 years – the data required for an analysis of this nature is numerous and analysis would be tedious and time consuming and would not be practical in a design office. A simple design tool that has been developed at the University of Auckland with funding from the Public Good Science Fund of the Foundation for Research, Science and Technology of New Zealand can be used for such life cycle analyses of design decisions (Mithraratne and Vale 2004).

Life cycle analysis model for New Zealand Houses

This model which is based on New Zealand embodied energy data and the useful life of building elements, materials and equipment, for generic construction types used in New Zealand, allows the designer to make changes and rapidly to see the differences between a number of possible designs, so that designers can evaluate their designs based on embodied energy, operating energy and life cycle energy. The decisions could further be evaluated on the initial and life cycle cost of the building. Most importantly, the model evaluates the total impact of the building in terms of energy and cost as it includes items such as appliances and furniture, which have not been included in the studies carried out so far in New Zealand. Simulations can be carried out either by selecting a sample file that best suits the project in hand and modifying it, or from scratch by generating a new file. Based on the complexity of the design, modeling could take from half an hour to several hours. Although, the model can be used for comparative analyses in terms of life cycle performance, as with any other simulation method, the model is not intended to be used to predict the life cycle performance of a particular design, as predicted performance often may not be matched by the actual.

The embodied energy data used are the most recent updates for New Zealand building materials by Alcorn (Alcorn and Wood 1998). Maintenance schedules are built into the model so that the embodied energy of maintenance can also be included over the life of the building. The user input is based on the quantities of material required to make the house and space heating energy requirement has to be calculated separately and transferred. This space heating energy requirement is further modified by the model depending on the fuel/heater type used, while other operating energy requirements are calculated by the model based on the number of occupants and the appliances selected.

2. LIFE CYCLE ENERGY ANALYSIS

This paper outlines an investigation using the model to explore the optimum specification for New Zealand house construction in terms of life cycle performance. The BIAC standard house (also known as Modal House of New Zealand), which was repeatedly used in the past by many researchers, is used here. The house is described briefly as follows:

level site
floor area 94 m^2 (14 m x 6.7 m)
3 bedrooms with open plan living, dining and kitchen
separate bath/Shower, WC, laundry
sloping ceiling with exposed rafters in living and dining areas and flat ceiling to other areas
12 lights and 16 power points.

Light construction

The lightweight timber framed house is the most prevalent specification in New Zealand (Vale et al. 2000). Specifications adopted for this most common construction used in this analysis as ‘light construction’ are as follows:

- particleboard floor on raised softwood framing, double-sided foil draped over floor frame as insulation;

- softwood framed walls with 94mm of glass fibre insulation within the framework, plasterboard internal lining with paint finish, fibre cement external cladding;
- pitched soft wood truss roof with corrugated metal cladding, flat ceiling lined with plasterboard, roof-ceiling space insulated with 75mm glass fibre;
- aluminium framed windows with single clear glazing.

Concrete Construction

The ‘high mass’ version of the timber-framed house, referred to in this analysis as ‘concrete construction’, replaced the light timber framed particleboard floor construction with a 150 mm thick concrete floor slab (the thermal mass) and 25 mm thick expanded polystyrene perimeter insulation to a depth of 500 mm.

Superinsulated Construction

In addition to these two construction types a highly insulated (or superinsulated) construction was added to the analysis to investigate the use of additional insulation in NZ houses, as use of extra insulation would raise New Zealand Standards nearer to those of Europe and North America. This highly insulated construction doubled the insulation in the common light construction to achieve an R-value of $4.4m^2C^0/W$ all around with double-glazing for windows. Specifications adopted for this highly insulated construction, referred to as ‘superinsulated construction’ in the analysis, are as follows:

- particleboard floor on raised softwood framing, with 200mm of glass fibre on a plywood soffit as insulation;
- softwood framed walls with 200mm of glass fibre insulation within the framework, plasterboard internal lining with paint finish, fibre cement external cladding;
- pitched soft wood truss roof with corrugated metal cladding, flat ceiling lined with plasterboard, roof-ceiling space insulated with 200mm glass fibre;
- aluminium framed windows with double clear glazing.

However, as New Zealand has been divided into 3 climate Zones as per the requirements of the New Zealand Standard on energy efficiency (NZS4218: 1996) with higher requirements for the cool Zone, the light and concrete constructions, which are commonly used in the Auckland region, do not satisfy the Building Code requirements for the colder climate in Christchurch. Therefore both light and concrete constructions were modified to suit the conditions in Christchurch by increasing the roof-ceiling insulation to 120mm thickness and by replacing single glazing with double-glazing. The resultant constructions are referred to in the analysis as Light-High and Concrete-High respectively.

While all five constructions were modelled for life cycle energy in both Auckland and Wellington, Light-High and Concrete-High constructions together with the superinsulated construction were modelled in Christchurch. The following assumptions were used to facilitate the analysis:

- the useful life of NZ houses is 100 years (Johnstone 1993);
- no major refurbishment is carried out during the useful life other than the normal maintenance to maintain the houses at a habitable level; and

- embodied energy of New Zealand building materials and construction practices remain static over the useful life time.

Heating energy requirement was modelled using ALF (Annual Loss Factor) version 3.0 (Stoecklein and Bassett 2000), for 18°C whole house heating with whole day heating (i.e. 7.00 to 23.00 hrs) and houses were also simulated for 8 orientations; North, North-east, East, South-east, South, South-west, West and North-west to investigate the influence of orientation on the heating energy requirement.

Analysis of the results

Generally, irrespective of the construction type and the location, life cycle energy is the least when the orientation i.e. the direction the living room faces, is from North through North-west to West, North-west being the best in Christchurch. However, North is the best in terms of life cycle energy in both Auckland and Wellington locations except for the superinsulated construction. In the Auckland climate, the superinsulated construction performs differently to this pattern with East and South-east orientations (11803 MJ/m^2) being the best in terms of 100 year life cycle energy closely followed by South-west orientation (11821 MJ/m^2). However, the difference is only 18MJ/m^2, which would be negligible when the accuracy of the simulation is considered. This also confirms earlier research (Vale and Vale 2000), which suggested that orientation was unimportant if the house was sufficiently insulated. The life cycle energy comparison for the Auckland location is as shown in figure 1 below.

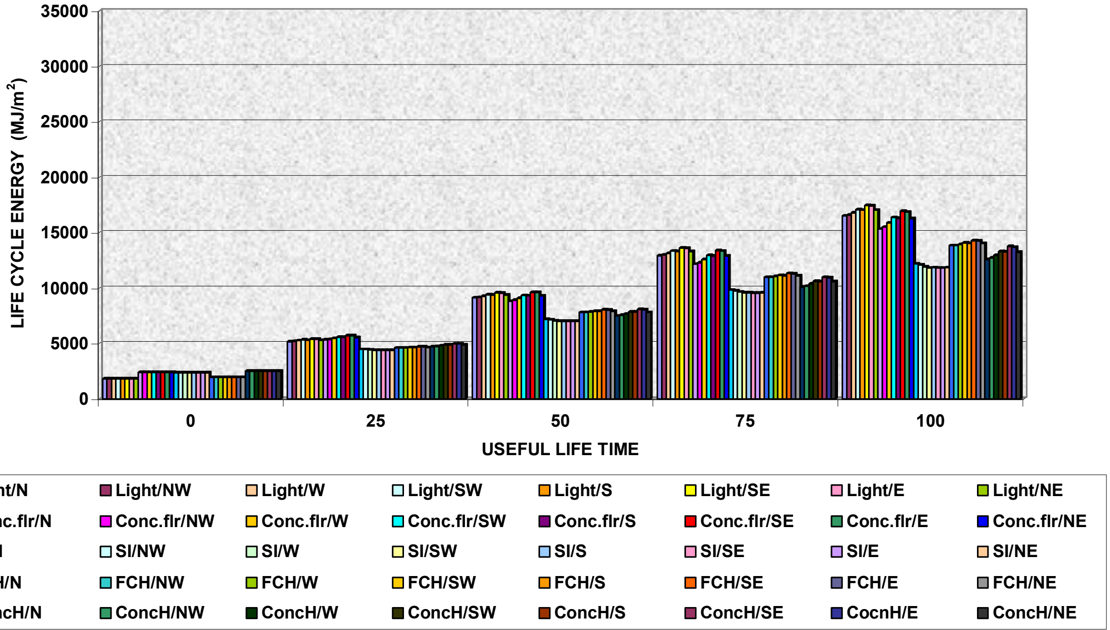

Fig. 1: Comparison of impact of orientation and construction type on the energy requirement in Auckland with whole day heating

However, the worst orientation in terms of life cycle performance varied with the location. In Christchurch it is East while in Wellington, both East and South-east orientations performed less well for all but Concrete-High construction type. East with 26350 MJ/m^2 was the worst for this construction type in Wellington closely followed by South-east with 26345 MJ/m^2. In Auckland the worst orientation is South-east for all but superinsulated construction for which it is North. However, for this construction type in Auckland the best (11803MJ/m^2) and the worst (12172MJ/m^2) 100 year life cycle energy varied only by 369MJ/m^2.

Comparison of impact of orientation and construction type on life cycle energy requirement in Wellington and Christchurch locations is shown in figures 2 and 3.

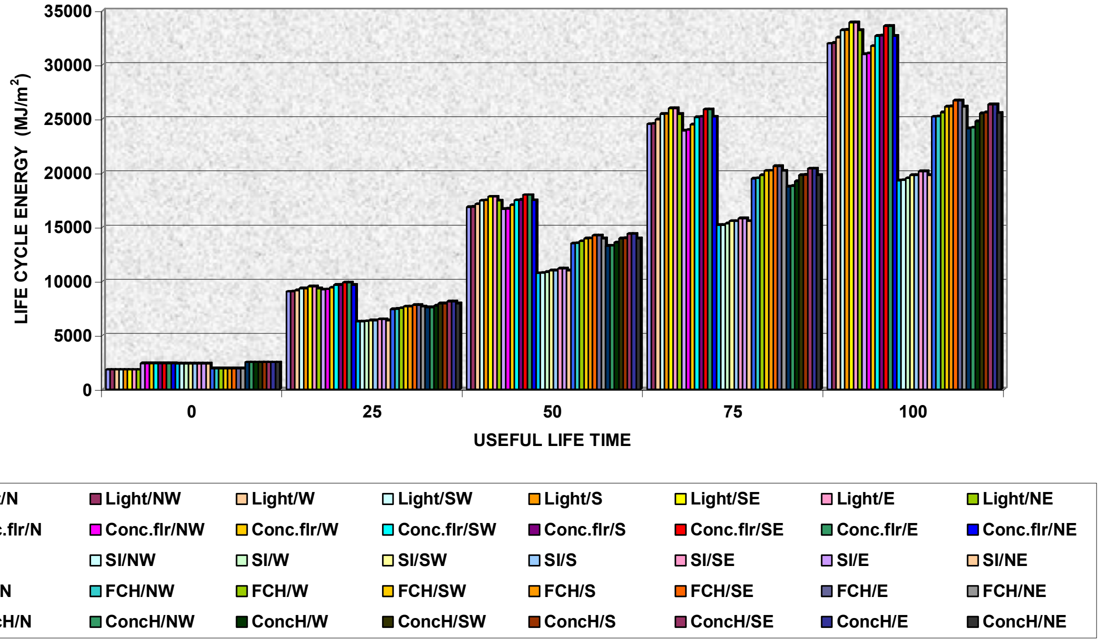

Fig. 2: Comparison of impact of orientation and construction type on the energy use in Wellington with whole day heating

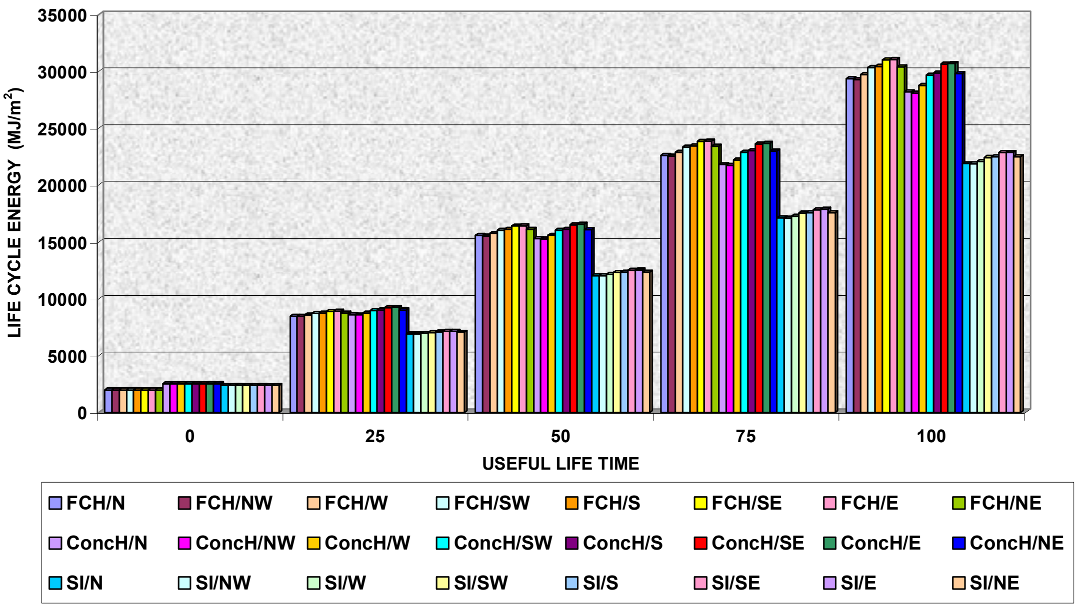

Fig. 3: Comparison of impact of orientation and construction type on heating energy use in Christchurch with whole day heating

In Wellington, with the worst orientation which is East the 100 year life cycle energy of the superinsulated construction type which is 20153MJ/m^2 is 68%, 67%, 33% and 31% less than the light construction with 33910MJ/m^2, concrete construction with 33609MJ/m^2, light-high construction with 26701MJ/m^2 and concrete-high construction with 26350MJ/m^2, respectively. In Christchurch, with the worst orientation which is East, the 100 year life cycle energy of superinsulated construction type which is 22866MJ/m^2 is 36% and 34% less than the light-high construction type with 31037MJ/m^2 and concrete-high construction type with 30675 MJ/m^2, respectively.

The common light construction type with 1818MJ/m^2 is the best in terms of initial construction energy. However, this is only 8% less than the light-high construction type with 1957MJ/m^2, while light-high construction type is 22%, 5% and 28% lower in initial construction energy compared to concrete construction type with 2392MJ/m^2, superinsulated type with 2058MJ/m^2 and concrete-high construction type with 2496MJ/m^2, respectively. If the worst life cycle performance for this construction type in Auckland, which is 14279MJ/m^2 is considered, it is 22% and 19% less than the light and concrete construction types, and 15% and 4% more than superinsulated and concrete-high construction types. In Wellington, if the worst performance is considered, the life cycle energy of light-high construction type is 27% and 26% lower than light and concrete constructions respectively, while it is 25% and 1% higher than superinsulated and concrete-high construction types, respectively.

In order to analyse the impact of different heating schedules on the life cycle energy requirement the house was then modelled with heating in the morning and evening (i.e. 7.00 to 9.00 hours and 17.00 to 23.00 hours) for the above locations and orientations. The results thus obtained are as shown in figures 4 to 6.

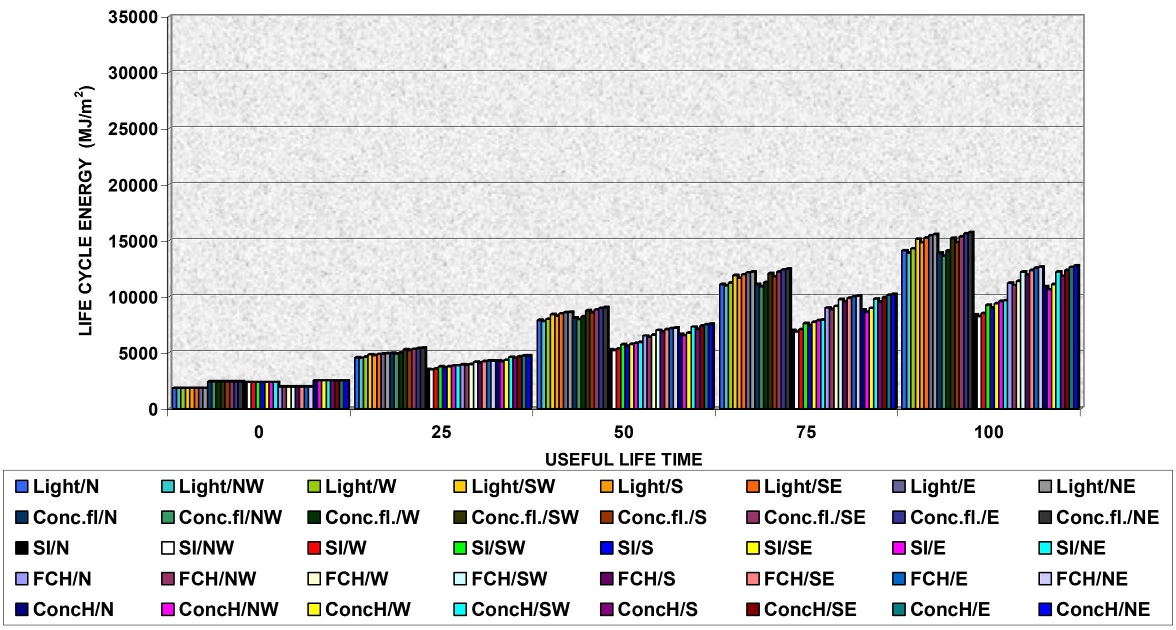

Fig. 4: Comparison of heating energy requirement for various construction types with intermittent heating in Auckland

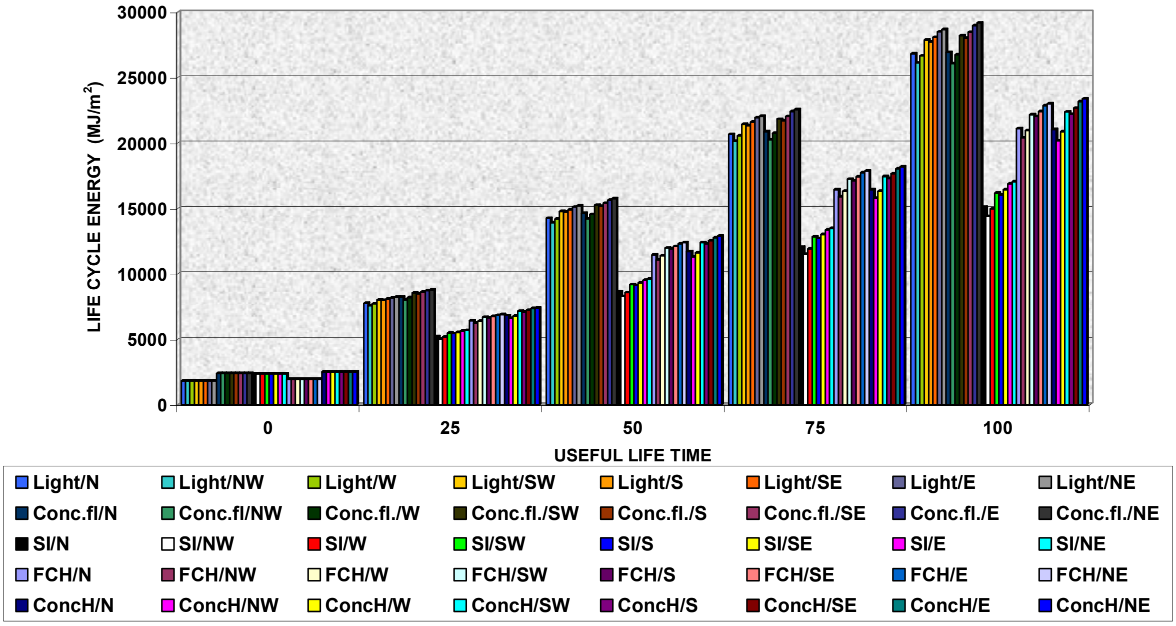

Fig. 5: Comparison of heating energy requirement with intermittent heating for various construction types in Wellington

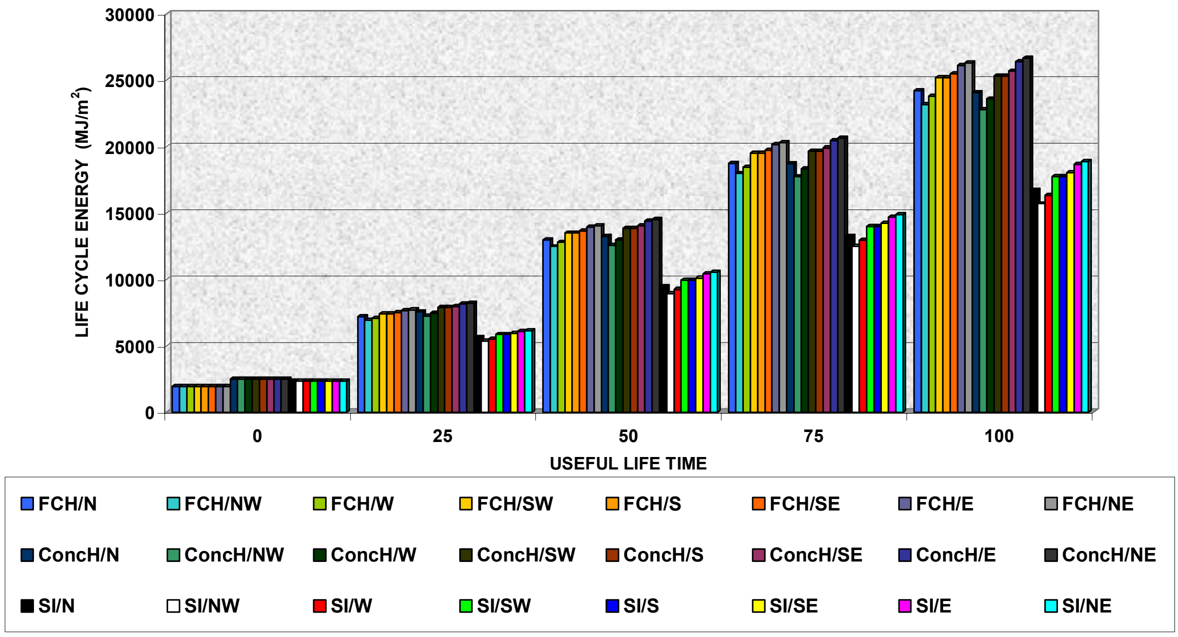

Fig. 6: Comparison of heating energy requirement with intermittent heating for various construction types in Christchurch

Analysis of the results

Even with intermittent heating, the best performance in terms of life cycle energy is with the orientations from North through North-west to West, North-west being the best and North-east being the worst for all three locations.

If the worst-case scenario which is North-east orientation and the superinsulated construction type is considered in the three locations, in Christchurch, the superinsulated construction type with 18882 MJ/m^2 life cycle energy is 39% and 41% lower than the light-high construction type with 26303MJ/m^2 and concrete-high construction type with 26655MJ/m^2, respectively. In Wellington, this construction type with 17042MJ/m^2 is 68%, 71%, 35% and 37% lower than light, concrete, light-high and concrete-high construction types. Life cycle energy under the above conditions for light, concrete, light-high and concrete-high construction types is, 28672, 29173, 23010 and 23380 MJ/m^2 respectively. With the same orientation in Auckland, the superinsulated construction type with 9659MJ/m^2 is 61%, 63%, 31% and 32% lower than light, concrete, light-high and concrete-high construction types. Life cycle energy under the above conditions is 15552, 15731, 12638 and 12744 MJ/m^2 respectively, for light, concrete, light-high and concrete-high construction types respectively.

Discussion

The results from these comparisons suggest that it may be beneficial to avoid orientations for the main living areas from South-east through East to North-east, and to use orientations from North through North-west to West whenever possible everywhere in New Zealand. This also suggests that while the morning sun is not of assistance in terms of useful solar energy the afternoon sun is. However, if superinsulated construction is used in Auckland, houses may disregard the orientation altogether.

The above comparisons also show that for a standard house of non-optimal design**,** (the BIAC house used for this analysis has not been designed as a passive solar low energy house) which forms the majority of the new constructions, the lightweight house with the superinsulation performs the best irrespective of the location, orientation and the heating schedule. In colder climates and with longer heating schedules although the life cycle energy requirement increased due to higher space heating use, the pattern remains the same. Although, the house with concrete slab on ground with timber frame did not seem to perform very well in this comparison it should be noted that this house had not specifically been optimised for passive solar efficiency. Anyway, enhancing the performance using passive solar design may be difficult to achieve in small sites in Auckland. However, if the light-high construction type specified for colder regions is used throughout New Zealand, significant savings in terms of life cycle energy could be acquired.

3. LIFE CYCLE COST ANALYSIS

However, the decision to use higher specification or additional insulation in the common house would depend on the cost of such improvements. Due to the current practice of changing ownership of New Zealand houses that happens approximately every seven years (Haberecht and Bennett 1999) designers perceive the client requirement to be for minimum initial cost and not minimum life cycle cost. However, the initial cost is only about 50% of the total life cycle cost for most buildings and life cycle costs could be used to inform designers and clients of the total cost implications of their decisions. The results of the life cycle cost analyses would depend among other factors, on the discount rate selected, whether inflation is included or not and the method of analysis selected. Due to the very long useful life of buildings it is not possible to estimate the future costs of building related activities and energy prices accurately. Therefore, the model uses current prices for building related activities and energy, to estimate the net present value of the total investment. The use of real costs, (i.e. current costs with no inflation included) provides an accurate comparison as the need to predict future rates of inflation is eliminated. Discounted from the date on which they occur to the beginning of the occupation and then added, these costs represent the total amount that has to be set aside today to finance the expenses throughout the useful life. Although it could be argued that this does not represent the true picture, provided the model is used for comparison of competing design alternatives it is possible to measure the life cycle performance in terms of relative life cycle cost. Anyway, it is not possible to use any model to predict the performance, as measured performance is often not matched by the predicted.

The life cycle cost of the construction types was considered in the three locations with whole day heating. The orientation with worst performance, i.e East for both Wellington and Christchurch and South-east for Auckland was selected for this analysis as it is not practical for a building code to specify the orientation of living spaces in a building. The average installed prices of building materials and constructions published by the New Zealand Building Economist (Wilson 2003) and current energy prices charged by Contact Energy (Lapsley 2004) were used for the analysis. Furthermore, as only the space heating component of operating energy is considered in this analysis with the assumption that the other operating energy requirements remain the same irrespective of the location, the line charge has been apportioned and added for an accurate analysis. Goods and Services Tax at the current rate of 12.5% has also been added to the final cost. Life cycle costs were calculated in terms of real discounted costs (inflation disregarded) with a real discount rate of 5%, and the results are as shown in Table 1. This life cycle cost represents the present value of the total investment required over the useful life to maintain different construction types at habitable level in the three locations. Figures 7, 8 and 9 compare the life cycle cost and life cycle energy for Auckland, Wellington and Christchurch respectively at current energy prices.

Table 1: Life cycle cost (NZ$/$m^2$) of BIAC house in 3 locations at current energy prices

Construction Type	**Auckland**		**Wellington**		**Christchurch**	
	Initial cost	**Life cycle cost**	**Initial cost**	**Life cycle cost**	**Initial cost**	**Life cycle cost**
Light	672.00	967.00	640.00	1042.00	-	-
Concrete	857.00	1085.00	816.00	1155.00	-	-
Superinsulated	855.00	1119.00	815.00	1130.00	727.00	1038.00
Light-High	731.00	1007.00	697.00	1053.00	621.00	985.00
Concrete - High	923.00	1131.00	880.00	1171.00	785.00	1090.00

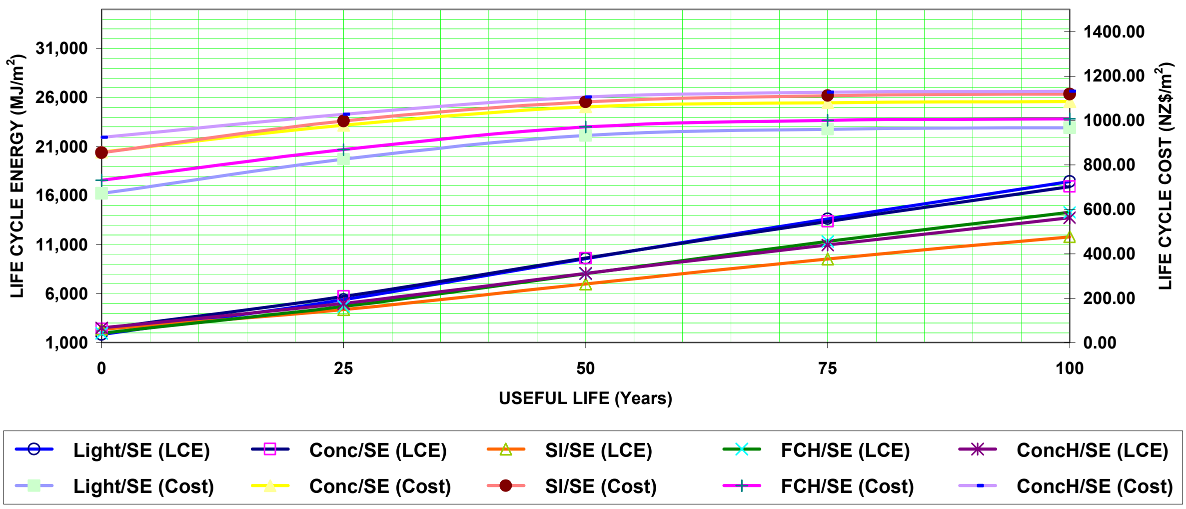

Fig. 7: Comparison of life cycle energy and cost at current energy prices in Auckland

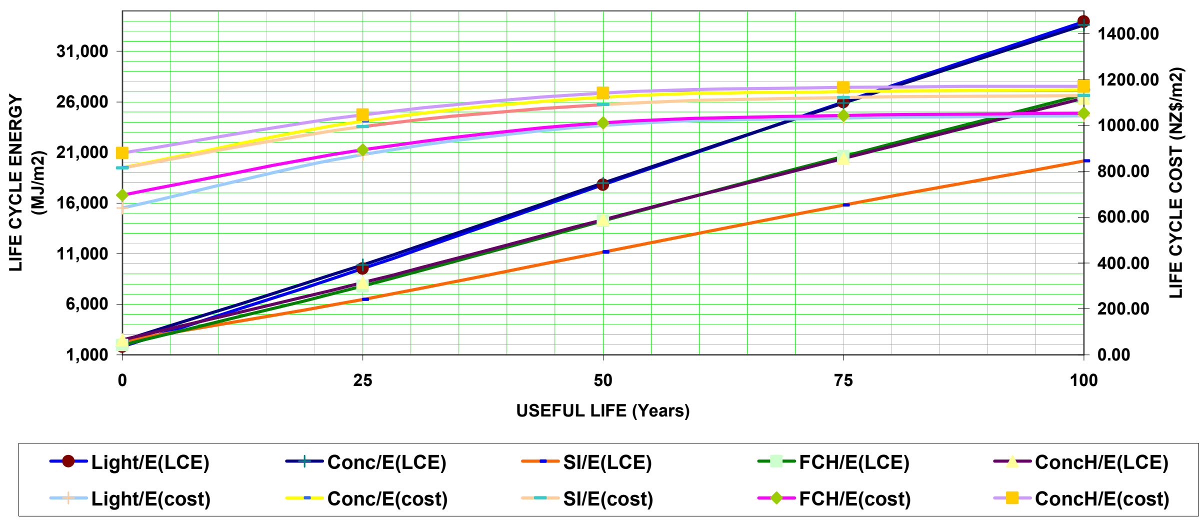

Fig. 8: Comparison of life cycle energy and cost at current energy prices in Wellington

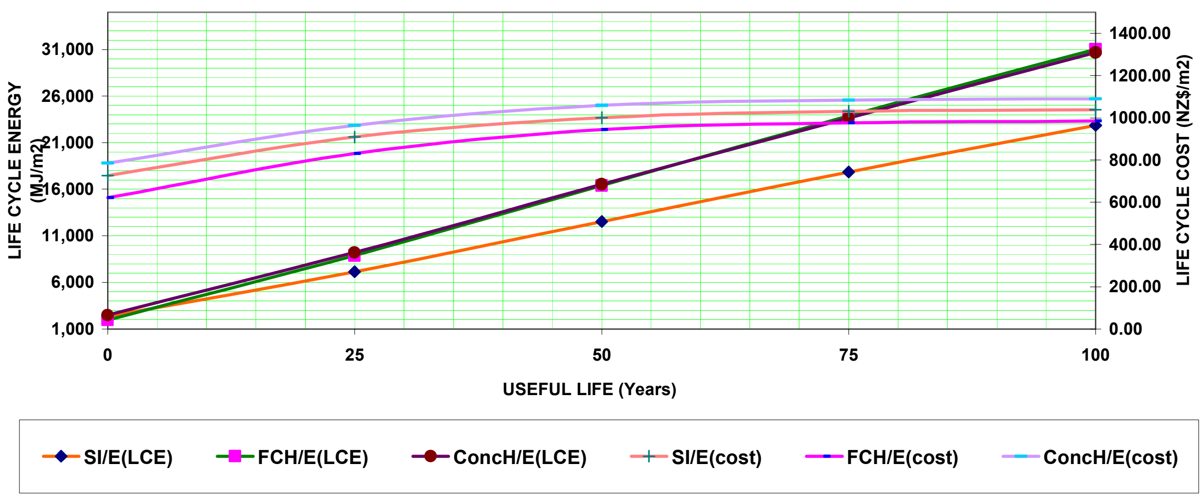

Fig. 9: Comparison of life cycle energy and cost at current energy prices in Christchurch

Analysis of the results

Average initial construction cost is the highest in Auckland with Wellington and Christchurch being 5% and 13% respectively lower. While superinsulated construction type is 21% and 14% higher than the light and light-high construction types respectively in terms of initial construction cost, it is also 0.2% and 8% lower than concrete and concrete-high construction types respectively. However if the life cycle cost of superinsulated construction type is considered in Auckland, it is 14%, 3% and 10% higher than the light, concrete and light-high construction types while it is also 1% lower than the concrete-high construction type. In Wellington, while the life cycle cost of superinsulated construction type is 8% and 7% higher than that of light and light-high construction types respectively it is also 2% and 4% lower than concrete and concrete-high construction types in terms of life cycle cost. In Christchurch although superinsulated construction is 5% higher in terms of life cycle cost compared to light-high construction type it is 5% lower when compared to concrete-high construction. In contrast, light-high construction type is the second lowest in terms of initial as well as life cycle construction costs in both Auckland and Wellington locations. While Christchurch appears to be the cheapest location in terms of life cycle cost for any construction type, Wellington is the most expensive. Although compared to Auckland cost of construction is less in Wellington, high cost of electricity seems to dictate the life cycle cost. In Wellington both unit costs and fixed costs are higher, with fixed costs being 28% higher than in Auckland.

In order to investigate the impact of an increase in energy prices on the life cycle performance all five construction types were modelled with 100% increase in current energy prices in all 3 locations. All though the pattern remains the same in Auckland, with 100% increase in energy prices the life cycle cost of light-high construction would then be only 2% higher than the common light construction type with a 32% reduction in life cycle energy use. Figure 10 compares the life cycle cost and energy in Auckland with 100% increase in current energy prices.

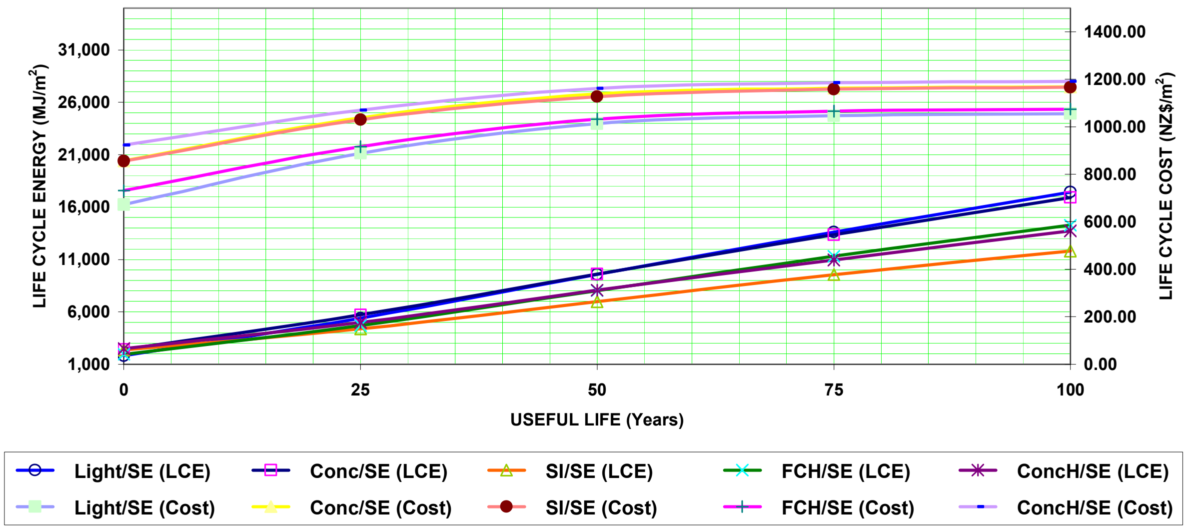

Fig. 10: Comparison of life cycle energy and cost with 100% increase in current energy prices in Auckland

If the current energy prices charged in Christchurch increased by 100% then the superinsulated construction type becomes 0.4% cheaper than the common light-high construction type in terms of life cycle cost with 36% reduction in life cycle energy use. Comparison of life cycle energy and cost with 100% increase in current energy prices in Christchurch is as show in figure 11.

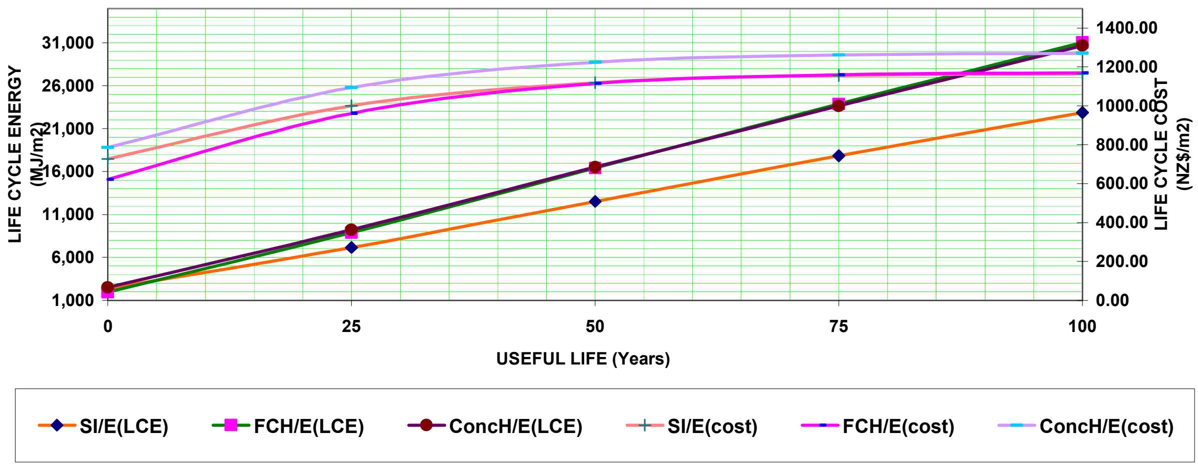

Fig. 11: Comparison of life cycle energy and cost with 100% increase in current energy prices in Wellington

Table 2 compares the life cycle cost of all construction types in Wellington with 100% increase in current energy prices. If the current energy prices increase by 100% in Wellington, then the light-high construction type would be cheapest in life cycle cost terms with light, concrete, superinsulated and concrete-high construction types being 3%, 11%, 2% and 9% respectively higher. In terms of life cycle energy light-high construction type would be 27% & 26% lower compared to light and concrete construction types while it will also be 25% and 1% higher respectively compared to superinsulated and concrete-high construction types as shown in figure 12.

Table 2: Life cycle cost of BIAC house in Wellington at 100% increase in current energy prices

Construction Type	**Heating Energy (kWh/a)**	**Life Cycle Cost (NZ$/m^2)**				
		Year 0	**Year 25**	**Year 50**	**Year 75**	**Year 100**
Light Construction	*5032*	640.00	1019.00	1189.00	1235.00	1247.00
Concrete Construction	*4918*	816.00	1161.001	1308.00	1345.00	1356.00
Superinsulated Construction	*2579*	815.00	1072.00	1191.00	1229.00	1239.00
Light-High Construction (FCH)	*3765*	697.00	1005.00	1154.00	1198.00	1209.00
Concrete-High Construction	*3627*	880.00	1153.00	1279.00	1314.00	1322.00

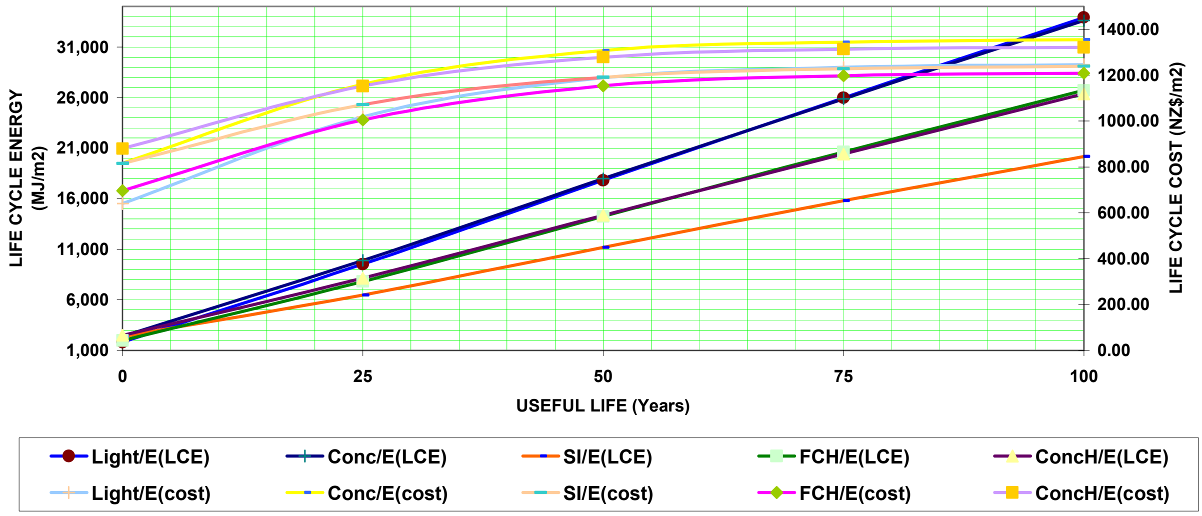

Fig. 12: Comparison of life cycle energy and cost with 100% increase in current energy prices in Wellington

4. CONCLUSIONS

The research demonstrates the importance of life-cycle analysis in the efficient use of limited resources in the residential building sector. Operating energy is a significant component of the life cycle energy of the average New Zealand house. Although constructions are currently evaluated based only on the initial construction cost, due to the unique nature of the residential sector in New Zealand the study shows that subsequent costs are equally important. Although the current electricity pricing structure does not encourage homeowners to save energy, price of electricity has a marked impact on the life cycle cost of a building.

The research also shows that at least the use of higher requirements currently specified for the colder region of New Zealand throughout the country could improve the performance of New Zealand houses at a marginal increase in initial construction cost. Use of additional insulation while enhancing the performance dramatically in terms of reduced energy use, higher internal temperatures and healthy internal environment, would also offer benefits over the house life as a buffer against changing energy prices.

5. ACKNOWLEDGEMENTS

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