Conversion of an Existing Housing Stock for an Ageing Population

Impact of furniture and appliances on life cycle energy (LCE)

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Abstract
There has been much discussion in the literature on how ageing in place can be made viable, given the ageing population in many developed societies, such as New Zealand. This paper discusses the potential for the subdivision of existing houses to make them more suitable and cost effective for older and retired people. It also looks at the impact such conversions would have on the embodied energy (EE) of furniture and appliances. In this study, EE analysis is used to measure the environmental impact of the furniture and appliances associated with each design option. The calculation is based on six hypothetical occupancy scenarios, two before and four after conversion. The EE of the furniture, appliances and tool items at various life stages is assessed for each scenario and a life cycle energy (LCE) figure per occupant calculated. Results from the EE calculation of the furniture, appliances and tools within the house before and after conversion, show occupancy is the key factor in whether resources can be saved using this approach. Two people living in the original house use slightly less EE related to furniture and appliances per person over 50 years than four people in the same house converted into two separate units. However, the same four people in a shared living arrangement have a 23% saving of life-time EE. This study shows that conversion of existing dwellings in New Zealand seems a way to make ageing in place viable but will not necessarily be more resource efficient. More research is needed to identify the appropriate size of dwellings, design characteristics and living arrangements for the 65+ age group which can accommodate their needs and preferences and at the same time be space and resource efficient.

Keywords: Ageing in place, Home modification, Lifetime homes, Embodied energy, Furniture and appliances.

1. Introduction
The 65+ age group in New Zealand has nearly doubled since 1981 and by 2050 a quarter of New Zealand’s population will be in this age group (Statistics New Zealand, 2015). Making appropriate housing choices is one of the most important decisions for this sector of society, many of whom are no longer in full time employment, while having such choices can lead to greater life satisfaction and better health (Office for Senior Citizens, 2013). According to Statistics New Zealand, the rate of home ownership for people aged 65+ is expected to decline (Office for Senior Citizens, 2013) while by 2050 numbers of older people with some form of disability are projected to increase by 60% (Statistics New Zealand, 2007). These two trends coupled with forecasts of more people in this age group living alone in the community (Office for Senior Citizens, 2013; Statistics New Zealand, 2015) lead to the growing need to address the issue of appropriate housing. One aspect of this is ageing in place rather than moving to a specially designed elderly residential facility, such as a retirement village. The aim of this study is to see what is possible when it comes to converting existing houses and through a life-cycle EE analysis including furniture and appliances, the resource implications of such conversions. McCamant & Durrett (2011) state that “from a sustainability perspective, rehabilitation of an existing building saves resources”, suggesting retrofit cohousing perhaps has lower lifetime resource use than new developments. Because it does not involve green field development but reuses existing built land it is probably more accessible and sustainable in terms of reducing resource use, construction materials, energy and waste and consequently, will lessen environmental impact. Earlier life-cycle energy studies have identified the critical factors influencing the lifetime energy and cost of residential buildings (Fay, 1999; Mithraratne et al., 2007) but their modelling of furniture and appliances has not considered using the house in different ways, such as for co-housing.

Both the size and content of houses could be significant for the environmental impact of housing modifications. The contents can be important as these items usually have short lives making their recurring EE more important. Given that the embodied energy of the building envelope and fittings has been often studied (Fay, 1999; Mithraratne et al., 2007; Crawford et al., 2002; De Angelis et al. 2013) this paper focuses solely on the EE of appliances, furniture and tools (FATs). A previous study found
the size of the house influences the number of furniture, appliance and tool items (Khajehzadeh, 2017) and hence the energy involved in them. In addition, this paper looks at the relationship between the number of people in the house and the EE of their FATs. The aim is to assist designers and end users to make informed decision in their selection of furniture and other house contents to minimise the EE of this often ignored aspect of housing.

2. Selection of house

In an investigation of New Zealand housing typologies and possible retrofit solutions by Ryan et al. (2008), ten house types representing 80% of the New Zealand housing stock were identified, one of which is the villa (1880–1920). BRANZ (2016) state, “villas were the most popular new home design in New Zealand from the 1880s through to World War 1.” In 2006 villas comprised 5.3% of the New Zealand housing stock (Page and Fung, 2008). In terms of villa plan layout, the living room and main bedroom typically face the street, with second and third bedrooms facing the side of the house, and service areas at the back (BRANZ, 2016). The central corridor, perhaps the dominant design feature of a villa, provides access to all rooms, including the bedrooms (Shaw, 1991). These villas were built almost entirely of timber (BRANZ, 2016). One storey villas are more common, although in more wealthy suburbs a significant proportion is two-storeyed (BRANZ, 2016). Shaw (1991, p.45) highlights the significance of the veranda in a villa stating, “The lean-to veranda became almost an obligatory feature”. Today BRANZ (2016) considers the villa to be a “popular renovation subject.”

In order to evaluate the feasibility of retrofitting typical New Zealand houses from a sustainability perspective, Page and Fung (2008) developed a scoring system based on a number of physical characteristics, such as roof and sub-floor access, and the likely replacement cycle of building components. In terms of ease of retrofitting and upgrading, they found the top ranked housing types were the villa, 1920s bungalows and 1940s to 1960s mass housing. Moreover, in a study of home repairs and maintenance in New Zealand, James and Saville-Smith (2010) found that older New Zealanders predominantly live in detached single-storey dwellings. This information justified the choice of a villa for investigating the retrofit potential for housing for an ageing population. An existing 214m$^2$ single story five bedroom (four bedroom + one office as specified in the original plan), built in 1909, was selected for conversion and the original drawings sourced from the relevant local authority (Figure 1).

![Figure 1. The original villa with possible furnishing plan](image-url)
3. Design considerations

3.1. Requirements for ageing in place

In a study of Australian dwellings, Judd et al. (2010) found that older residents used spare bedrooms for activities other than sleeping, such as (from more to less frequent) home office/study, guest bedroom, hobbies, storage, ironing, and reading. Their research found a high proportion (95%) of respondents had one or more bedrooms, and 63% two or more, not used regularly for sleeping, (Judd et al., 2010). In a time-use study of New Zealand houses, Khajehzadeh (2017) found older people made more use of a study than all other age groups. It seems, therefore, that multi-purpose spaces could be suitable for those aged 65+. In 2013, nearly 80% of this age group who lived in private dwellings were in small (single or couple) households (Statistics New Zealand, 2015).

The integration of nature into the built environment has been found to enhance wellbeing and quality of life, and thus human health (Beatley, 2011; Husk et al., 2013). This has led Yavari et al. (2016) to suggest the integration of indoor spaces, such as living areas, with outdoor space or a deck could encourage use of the outdoors and provide pleasant places for social engagement. This could be even more significant when it comes to designing smaller dwellings for older people (Yavari et al., 2016). Khajehzadeh and Vale (2016a) found on average New Zealanders spend 0.55 hours/day at home outdoors in summer, with the corresponding figure for the 65+ sample being 1.09 hours/day. Therefore, in the conversions for this study, additional private and shared decks were included with their necessary furnishings, such as a barbeque, chairs and tables.

Statistics New Zealand (2013) suggest there is an increasing demand for communal dwellings driven by the ageing population. Communal residential buildings, including co-housing, have also been identified as a sustainable approach to accommodation for people, as these provide a supportive and communal environment (McCamant & Durrett, 2011; Sanguinetti, 2012). Brenton, (2013) sees creating senior cohousing through retrofitting as an alternative for the older occupants of existing buildings, illustrating this with an example from the Netherlands in which a group of older people living in an apartment building kept a flat in their block untenanted to be used as a “common house”. This created a supportive and sociable community without the need for moving. Creating housing where residents could share spaces when required might also give them the opportunity to take advantage of having company and support through use of such shared spaces. From a sustainability view point, shared spare rooms could save resources in terms of the energy involved in using them (heating), their maintenance and furnishing. In addition, smaller units which are easy to heat and maintain would also make ageing in place more viable.

3.2. Design standards

Design standards have been developed to promote access in the built environment for those with disabilities. The implementation of these standards is widely acknowledged to enhance the quality of life for all people particularly the elderly and those with disabilities. Lifemark Design Standards (LM) were first produced in 2012 by the New Zealand organisation Lifetime Design Ltd, followed by a second version in 2016. Their aim was to assist an ageing population to meet their changing needs in more suitable houses, although a ‘lifemark house’ is also claimed to be beneficial for occupants and visitors of every age and ability (Lifetime Design Limited, 2012). LM, is a NZ version of the concepts of lifetime home and universal design although another investigation as part of this study found a lack of detailed agreement when it comes to designing dwellings for an ageing and less mobile population (Yavari and Vale, 2017).

Lifemark Design provides a star rating and points system within which every ‘lifemark’ home has to meet the requirements specified in one of the three categories, including a 3-star lifemark home being fully adaptable in the future at minimal cost and a 5-star lifemark being fully accessible (Lifetime Design Limited, 2012). Giving the choice of a 3-star or 5-star rating enables the designer to meet the current and future needs of the residents and make a decision based on their situation.
Since the present study is conducted in New Zealand, the standards implemented in redesigning the case studies dwellings must comply with NZ standards. Because this research is concerned with existing dwellings the LM 3-star standard was used as the starting point. However, in some instances this was supplemented with aspects from UD and LTH.

Based on criteria discussed above and according to 3 star NZ Lifemark, two schemes were prepared with different degrees of sharing.

Scheme A: This is a conversion into two single units with some shared spaces. The first is a one-bedroom unit of 90.5m² with a cellular plan arrangement and an 11.2m² deck and the second a smaller one-bedroom unit of 66m² with 17.5m² deck. The shared area of 57.5m² comprises corridor, entrance, guest suite and study/sitting room with a 19.8m² roofed deck (Figure 2). The larger unit has also a private entrance.

Scheme B: This is a conversion into two en-suite bedsits of 26.3m² and 25.9m². There is a shared deck of 20m² and shared kitchen, combined dining/living room, corridor, guest room, study/hobby room, visitor’s bathroom and laundry with the collective area amounting to 161.8m². Each bedsit has its own bathroom, TV and sitting area (Figure 2). The smaller bedsitting room has also a private deck of 8.7m².

4. EE of furniture and appliances

Life Cycle Assessment (LCA) is “a science-based, comparative analysis and assessment of the environmental impacts of product systems” (Klöpffer, 2014, p.2). Less attention has been given to furniture, fittings and appliances in many life cycle studies (Khajehzadeh and Vale, 2016b; Treloar et al., 1999).

In this study, the EE of furniture items, appliances and tools was calculated to represent the environmental impact of the fit-out of each design option. The EE is based on 6 scenarios:

Scenario 1 - The original house is occupied by a couple for 100 years.

Scenario 2 - The original house is occupied by a couple for 50 years, then without any change is occupied by a single person for 50 years.

Figure 2. Left: scheme A (scenarios 3, 4 and 5); right: scheme B (scenario 6)
Scenario 3: The original house is occupied by a couple for 50 years, when the house is converted to scheme A. Two couples occupy units 1 and 2 and use the shared spaces for 50 years, so four people now occupy the modified house.

Scenario 4: The original house is occupied by a couple for 50 years, when the house is converted to scheme A. Two single persons occupy units 1 and 2 and use the shared spaces for 50 years, so two people now occupy the modified house.

Scenario 5: The original house is occupied by a couple for 50 years, when the house is converted to scheme A. Two single persons occupy units 1 and 2 for 50 years, and a single person (as a carer/boarder) occupies the ‘shared spaces’ as private unit, so three people now occupy the modified house. The shared spaces in scheme A were refurnished without any change to the plan, through the installation of a mini kitchen in the living area, to allow for the shared space to become a third unit.

Scenario 6: The original house is occupied by a couple for 50 years, when the house is converted to scheme B. This couple occupies bedsit 1 and bedsit 2 is occupied by another couple who are relatives (such as grandchildren saving up to buy their own home), so four people occupy the modified house and share the living room, kitchen/dining, laundry, guest room, study/office and decks.

5. Calculations: method and assumptions

Information about the types of furniture, appliances and tools people have in their houses come from Khajehzadeh’s (2017) study, which investigated the number of furniture, appliance, and tool items (FATs) found in New Zealand houses. Using the Statistics New Zealand (2014) room standard, the original house with 4 bedrooms and an office is considered to be an 8 room house. For calculation purposes, for scenarios 1 and 2, FATs data from Khajehzadeh’s study for participants who lived in an 8 room house including single and couple households were extracted.

For each proposed scheme (scenarios 3-6), a detailed furnishing plan was drawn up. This proposed plan was then checked with the findings from Khajehzadeh’s survey. Based on Statistics New Zealand (2014) room standard, both units in scheme A are 4 room dwellings even though unit 2 has an open plan arrangement. A table of 129 items was established using data from Khajehzadeh’s survey of participants who lived in 4 room houses, including single (n=4), couple (n=4) and all households (n=9). Given the aim of the conversion was incorporation of LM standards, it was decided to lose furniture items which would make manoeuvring through various indoor spaces difficult. This was done by providing a clear turning circle of 1500mm for living spaces and bedrooms. The only major difference between the survey results and the proposed furnishing plan for a 4 room house was the number of outdoor furniture items included. In the conversion proposals, private and shared decks were added to the northwest façade of the original house and a reasonable number of furniture items for outdoor activities were assumed. For the shared spaces, the layout and function of the spaces drove the selection of furniture. Scenario 5 is an example of different furniture in the shared area. A part of shared area is used as mini kitchen in this scenario while in scenarios 3 and 4, shared spaces are used as a guest room and study/sitting room.

Khajehzadeh’s (2017) investigation of 260 New Zealand households identified 140 furniture, appliance and tool items in New Zealand houses (apartments were excluded in this study). Based on the method described above, 69 items were used in this study. These comprise 33 appliances, and 32 furniture and 4 tool items, used both indoors and outdoors. The EE of each furniture, appliance and tool item was calculated using the Treloar (1998) cost based method. In an EE analysis of fixtures, fittings and furniture for Australian office buildings, Treloar et al. (1999, p.407) used this method to give a comprehensive image of the “energy implications of the demand for new fixture, fittings and furniture” and “better indications of the environmental loadings attributable to the manufacture of new fixture, fittings and furniture to satisfy demand”. The Treloar method uses an estimated 8MJ/$ for furniture and 10MJ/$ for appliances with the minor difference between the Australian and New Zealand dollar being ignored. This method has previously been used by Khajehzadeh (2017), Vale and Vale (2009), Mithraratne et al. (2007) and Fay (1999). Using the median price and the useful life of items from Khajehzadeh (2017) the initial (Year 0) and recurring EE of furniture, appliances and tool was calculated for the six scenarios. It was assumed that furniture and appliances are replaced at the end of the useful life of each item.
6. Results

Using the methods discussed earlier, the EE of furniture, appliances and tools items was calculated for scenarios 1-6 at various life stages (Table 1). To identify the impact of before and after conversion for each scenario, the respective EE for the last 50 years is shown in the last column of Table 1. As in previous studies (Khajehzadeh, 2017; Treloar et al., 1999; Yavari et al., 2018), findings from this study also show that the EE of furniture and appliances is a very significant component of the life cycle energy of a building.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>EE of furniture, appliance and tool items (GJ) at various life stages</th>
<th>The last 50 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>397.7</td>
<td>1974.2</td>
</tr>
<tr>
<td>2</td>
<td>397.7</td>
<td>2302.3</td>
</tr>
<tr>
<td>3</td>
<td>397.7</td>
<td>2606.4</td>
</tr>
<tr>
<td>4</td>
<td>397.7</td>
<td>2531.4</td>
</tr>
<tr>
<td>5</td>
<td>397.7</td>
<td>2591.1</td>
</tr>
<tr>
<td>6</td>
<td>397.7</td>
<td>2450.0</td>
</tr>
</tbody>
</table>

7. Discussion

7.1. Design characteristics and the EE energy implications of furniture and appliances

The characteristics and size of the original house provide opportunities for various design solutions for ageing in place. These include various degrees of sharing, different numbers of occupants, different ways furniture can be accommodated within the proposed designs, and different living arrangements (open or cellular plan layout). As can be seen in the Table 1, by converting the original house into schemes A and B, the EE of furniture and appliances increases over the life of the house. Considering scenario 1 as the base scenario, scenarios 3 and 5 have the most increase in the EE of furniture and appliances respectively (101.5% and 96.8%), being almost twice the EE of scenario 1 in the last 50 years (Table 2). These increases are mainly caused by the different plan arrangements because the house is converted to accommodate more than one household. This shows that for the same house size, the number of households influences the number of furniture and appliance items and thus, the consequent EE. It should be noted that for scenario 5, the smallest possible number of appliance and furniture items were considered for the third household (boarder/carer).

In addition, a comparison between scenarios 3 and 6 suggests that with the same house size, household size (a couple) and number of total occupants (4 persons), the occupants’ life style can decrease the EE of furniture and appliances. Designing communal spaces where occupants share resources can contribute to a reduction in EE (scenario 6). Findings from this study shows that for the same household size, sharing spaces in scheme B (scenario 6) has reduced the EE of furniture and appliances by 23% compared to scheme A (scenario 3). In a similar study in the England and Wales, Williams (2007) investigated a number of design solutions including ecological homes (incorporating energy-efficiency measures and renewable energy technologies), communal homes (sharing resources between household members) and collaborative dwellings (sharing resources within a community such as in co-housing). She found substantial resource savings for those living in both shared and co-housing arrangements (in terms of land, direct energy and household goods), mainly due to sharing resources in daily living. She estimated average resource savings of 44% and 57% in communal and collaborative housing respectively (Williams, 2005 in Williams, 2007). In addition to sharing resources it seems these types of housing encourage a wide range of environmental behaviours in terms of energy conservation and waste recycling.

Table 2 summarises how moving from scenario 1 to scenarios 2, 3, 4, 5 and 6 affects the EE in furniture, appliances and tools for the last 50 years.
Table 2. Changes in EE of furniture, appliance and tool items by moving from scenario 1 to scenarios 2, 3, 4, 5 and 6

<table>
<thead>
<tr>
<th></th>
<th>% change by moving from Scenario 1 to 2</th>
<th>% change by moving from Scenario 1 to 3</th>
<th>% change by moving from Scenario 1 to 4</th>
<th>% change by moving from Scenario 1 to 5</th>
<th>% change by moving from Scenario 1 to 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE of furniture, appliances and tools</td>
<td>-3.2%</td>
<td>+101.5%</td>
<td>+69.8%</td>
<td>+96.8%</td>
<td>+55.8%</td>
</tr>
</tbody>
</table>

A comparison between scenario 1 (couple household) and 2 (single household) shows only a slight difference in the number of furniture items and appliances, with a 3% change in EE (Table 2). This suggests that in large houses, household size is not a major influential factor for the EE of furniture and appliances. This aligns with the results from Khajehzadeh’s (2017) investigation suggesting that number of furniture, appliance and tool items is affected by house size not household size.

7.2. Occupancy and EE of furniture, appliances and tool items

Figure 3 illustrates the EE of furniture, appliances and tool items for the whole dwelling and per person for the last 50 years for each scenario. Apart from design characteristics as discussed earlier, tables 1 and 2 suggest the number of person(s) in the dwelling is the influential factor in the EE of FATs. Considering just the last 50 years, while in scenarios 1 and 2, 2 and 1 persons live in the original house, after conversion scenarios 3, 4, 5 and 6 can accommodate respectively 4, 2, 3 and 4. The total EE used for furniture, appliances and tool items over the last 50 years for each scenario was thus divided by the number of occupants (Figure 3). As expected one person living in the whole house uses the most EE for furniture and appliances (scenario 2) but energy reductions from having more people in the house depend on the type of conversion. One problem with ageing in place in small households of one or two people is that research suggests these “…are less efficient in terms of resource use per capita than larger households” (Liu et al., 2003 in Williams, 2007, p.331). Williams (2007) sees the growth in one-person households in England and Wales as leading to an increase in domestic resource consumption of energy, water, land and materials, something she considers the UK has in common with many developed countries.

Figure 3. EE of furniture, appliance and tool items and EE per person over 50 years for each scenario

Figure 3 suggests that while scenarios 3 and 6 for schemes A and B accommodate 4 persons, scenario 6 has the least energy use for furniture and appliances mainly due to sharing resources in the last 50 years, as suggested by other researchers (William 2007; McCamant & Durrett, 2011). However, moving from scenario 3 to scenario 6, or from private to shared living arrangements with the same occupancy rate, saves 23% of EE in furniture and appliances. Nevertheless, leaving 2 people in the original house is slightly better than having 4 people live in scheme A (two private units) (Figure 3). McCamant & Durrett (2011, p:15) believe that “the sharing of resources gives all residents access to a wider variety of convenience at a lower cost.
per family than is otherwise possible”. They also give a number of instances of sharing between cohousing households, including sharing spaces such as a laundry, guest room, and items like essential tools and a lawnmower through having a common workshop, as well as sharing newspapers and magazines, camping equipment and other things used less often. In some cases, cars, sailboats and vacation houses were shared between two or more households (McCamant & Durrett, 2011).

8. Conclusion
This study shows that conversion of existing dwellings in New Zealand seems to be a good idea to make ageing in place viable but would not necessarily be more resource efficient. More research is needed to identify the appropriate size of dwellings, design characteristics and living arrangements for the 65+ age group which can accommodate their occupational needs and preferences and at the same time be space and resource efficient.

As discussed earlier, the EE of furniture, appliances and tools comprises a significant proportion of total energy used over the life of a dwelling. Therefore, the acceptability of reusing, recycling or refurbishing furniture and the consequence energy implications should also be investigated.

Acknowledgement
I am grateful to HOPE and Selwyn foundations for their generous scholarship. The HOPE – Selwyn Scholarship in Ageing Research and grant from Victoria University of Wellington enabled me to attend the ISDRS2018 conference. The significant contribution and support of Dr. Iman Khajehzadeh of the Open Polytechnic of New Zealand is also acknowledged.

References


