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Summer Temperatures in New Zealand Houses

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Living room summer temperatures in 400 New Zealand houses have been analysed by house age, climate and glazing to explore key drivers. Summer temperatures appear to be strongly influenced by the age of the house and the local climate – together these variables explain 51% of the daytime (9am to 5pm) living room temperatures. Thermal modelling suggests that as the glazing area increases in proportion to the floor area, living room temperatures will increase. In the monitored houses, in addition to the glazing area the occupant behaviour (e.g. operation of windows) was found to also play a major role in determining the daytime maximum temperatures. Newer houses tend to have higher summer daytime living room temperatures than older houses, raising questions about their ability to adapt to potential climate changes. Additional analysis and modelling is being undertaken to further explore these issues. House data and temperature readings (10 minute) are from the Household Energy End-use Project (HEEP) which has monitored a statistically representative sample of New Zealand houses.

Keywords: Household Energy End-use Project (HEEP), temperatures, residential

1. INTRODUCTION

In this paper, daytime, summer living room temperatures in a random sample of New Zealand houses are explored and three areas that influence temperatures – climate, house age and glazing – are examined.

Data has been taken from the HEEP project which holds data on 397 houses from Kaikohe to Invercargill giving a statistically representative sample of the country. Annual reports have provided preliminary results through the project (e.g. Isaacs et al 2005), and the most recent Executive Summaries are freely downloadable from the BRANZ Ltd website www.branz.co.nz.

Temperatures are recorded at two different heights in the living room and one height in the master bedroom on a 10 minute basis. Sensors are placed out of direct sunlight and heating sources, and data is checked thoroughly to remove any inaccuracies. Monitoring of each house is carried out for a period of approximately one year.

This paper focuses on living room temperatures, but exploratory work has been undertaken for bedroom temperatures which were found to be on average slightly cooler than the living room temperature. The summer months are December, January and February, and unless otherwise stated the temperatures are between the hours of 9am and 5pm.

Although summer temperatures would normally be considered to be acceptable without additional heating, the HEEP data shows that 12 houses (approximately 3% of the sample) are reportedly heated throughout the whole year, with half of these in the Otago/Southland region.

Analysis of indoor monitored summer temperatures was included in the *Survey of household* *electricity consumption 1971-72 – Report on the temperature/insulation study* (NZ Department of Statistics 1976). They found 24 hour average temperatures over a two month summer period (February-March 1972) of 20^{o}C to 21^{o}C.

2. SUMMER HOUSE TEMPERATURES

The large majority of New Zealand houses are not heated or cooled during summer months. The indoor temperature therefore is not as dependent on energy use as winter temperatures. The house construction (such as mass, insulation, airtightness) becomes more important, as does the climate and occupant behaviour.

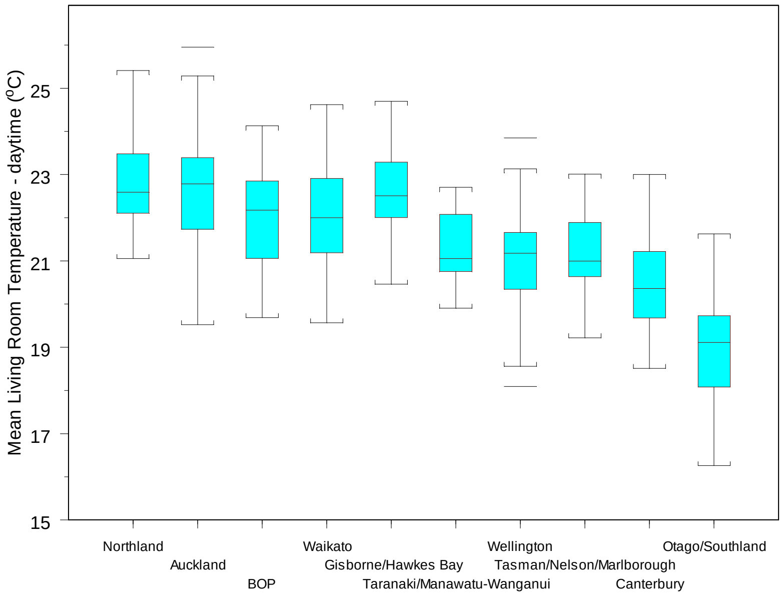


Figure 1: Mean temperatures inside New Zealand living rooms by region

Figure 1 shows the mean living room temperatures for all monitored houses from December to February, between the hours of 9am and 5pm by regional councils (some councils are combined). It should be noted that some council areas may not be representative due to the small number of houses measured in the area. The x-axis is in north to south order – the further south, the cooler the median (horizontal bar in centre of box) temperature. This is discussed further in Section 3.1.

	Living Room			Bedroom		
Mean temperatures	9am-5pm	Midnight-7am	24hrs	9am-5pm	midnight-7am	24hrs
Lowest (^{o}C)	16.3	15.2	16.4	15.9	15.3	16.1
Highest (^{o}C)	25.4	23.6	24.6	24.3	23.8	24.0

Table 1: Range of mean temperatures for houses

The range of summer temperatures for both the living room and master bedroom are given in Table 1. It should be noted that the houses with a higher 24 hour mean temperature are not necessarily the same houses that have higher temperatures during the daytime. The reasons for this have yet to be investigated, but could possibly relate to the house thermal mass. The houses with the higher 24 hour mean temperatures tend to be in Auckland and Northland, while those with higher daytime temperatures are spread from Hawkes Bay to Northland.

This paper is focused on the living room temperatures. Although there is very little difference between the living room and the bedroom temperature, the living room is generally slightly warmer. The largest difference between the living room and bedrooms occurs during the evening and daytime periods where there is a 0.6^{o}C difference in the means across all houses. New Zealand houses have randomly orientated windows (on average about 25% of the total glazing is in each compass direction), which may explain the small temperature difference between bedrooms and living rooms.

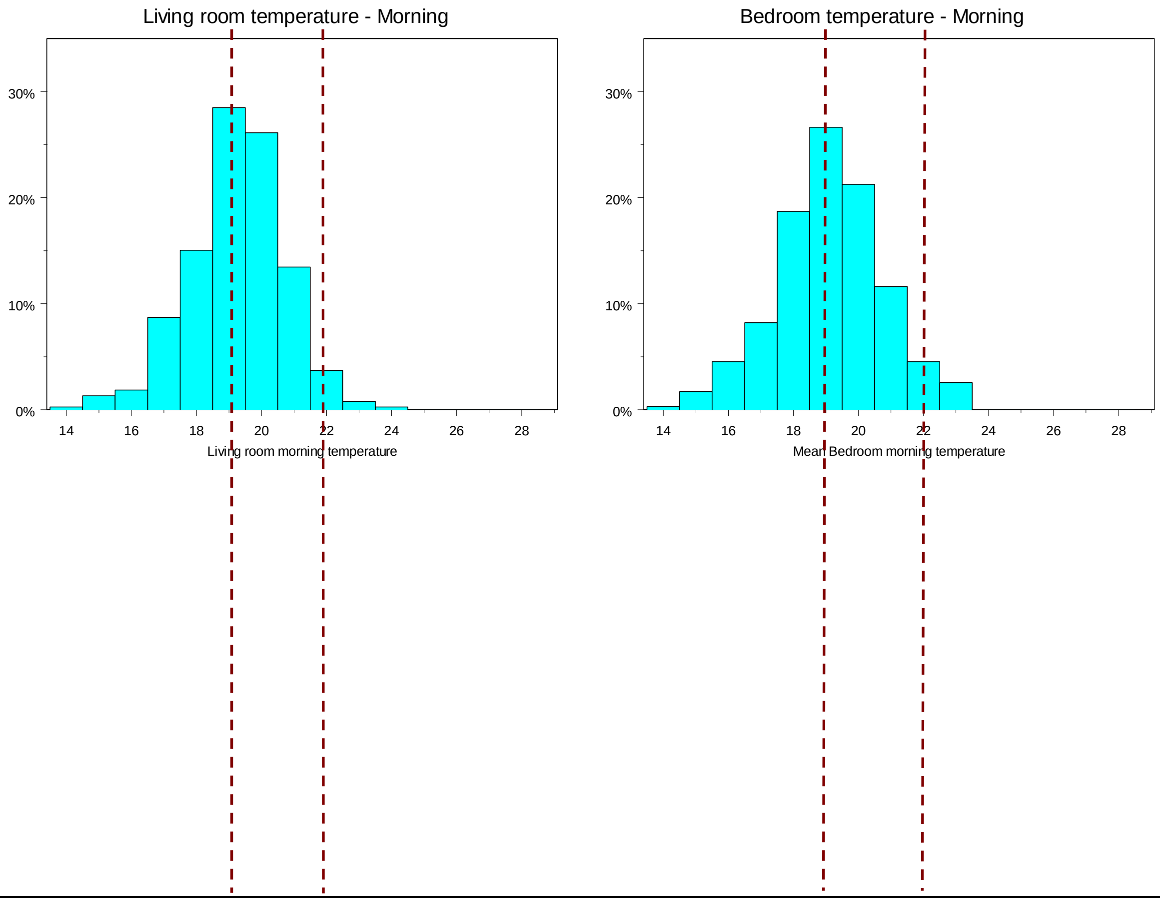
2.1. Differences during the day

The monitoring found that from morning (9am) to evening (5pm) both the living room and bedroom temperatures increased on average by ~4^{o}C, and they decrease by a similar amount during the night. Table 2 shows the change in temperatures between four chosen time periods: morning is 7am to 9am; day is 9am to 5pm; evening is 5pm to 11pm; and night is midnight to 7am. Table 2 also shows the close relationship between the living room and bedroom temperature changes. The influence of overnight internal gains (people, lights etc) can be seen with the bedroom temperatures decreasing slightly less overnight than the living room. Conversely, there is a higher increase in the living room temperature from during the morning as the occupants move from the bedroom (night) to the living room (morning).

	Temperature difference between the means for all houses			
	Morning to Day	**Day to Evening**	**Evening to Night**	**Night to Morning**
Living room (^{o}C)	2.5	1.4	-2.9	-1.1
Bedroom (^{o}C)	2.1	1.4	-2.4	-1.0

Table 2: Temperature changes during the day

This distribution of temperatures and the shift between morning and daytime is shown in Figure 2. The distribution of living room temperatures are shown in the two graphs on the left and the distribution of the bedroom temperatures are shown with the two graphs of the right. The top two graphs show the distribution of morning temperatures through the houses and the lower two show daytime temperatures.



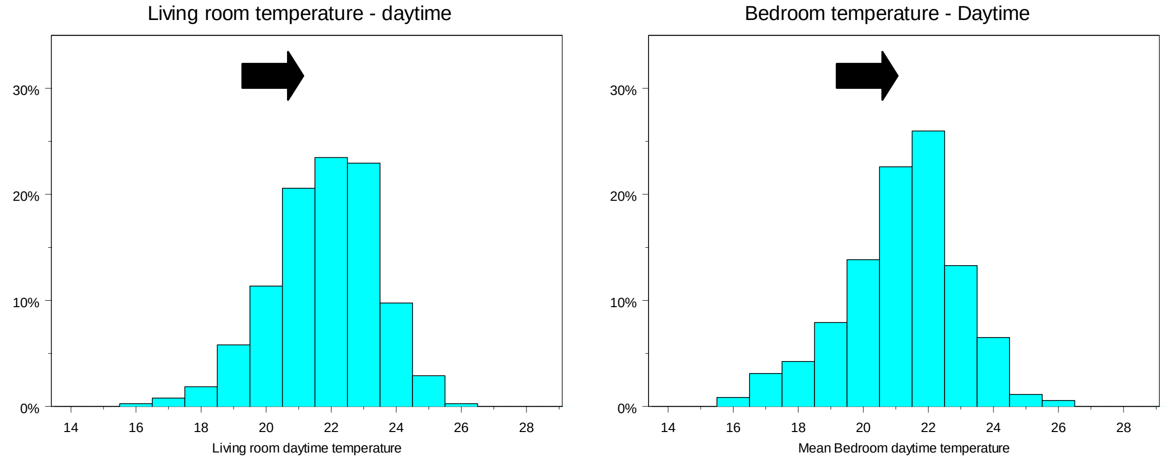


Figure 2: Distribution of temperatures for living and bedroom during morning and daytime

It can be seen that as the day progresses there is a shift in the temperature distributions for both the living room and bedroom, with the mean increasing from 19.3°C to 21.8°C for the living room, and the bedroom from 19.1°C to 21.2°C.

2.2. How warm does it get?

Daytime mean temperatures (Figure 1) range from ~20°C to ~25°C, apart from Otago/Southland with a mean of 16°C. Apart from Otago/Southland, these would appear to fit with the generally accepted comfort ranges. Figure 1 also shows that there is a wide distribution of mean temperatures, suggesting that at least part of the day is spent outside this range. Figure 3 shows the proportion of time between 9am and 5pm that the living room temperatures are under 20°C, between 20°C and 25°C, and over 25°C.

Nearly four out of five houses (78%) spend more than half of the day between 20°C and 25°C. Of the other houses (22%), over half of them (13%) spend more than half the day below 20°C, and only 1% spend more than half the day above 25°C.

Over all the houses, the majority (80%) spend less than 25% of the summer daytime (two hours per day) at temperatures over 25°C. However, 1% spend over 50% (four hours per day) of the summer daytime above 25°C.

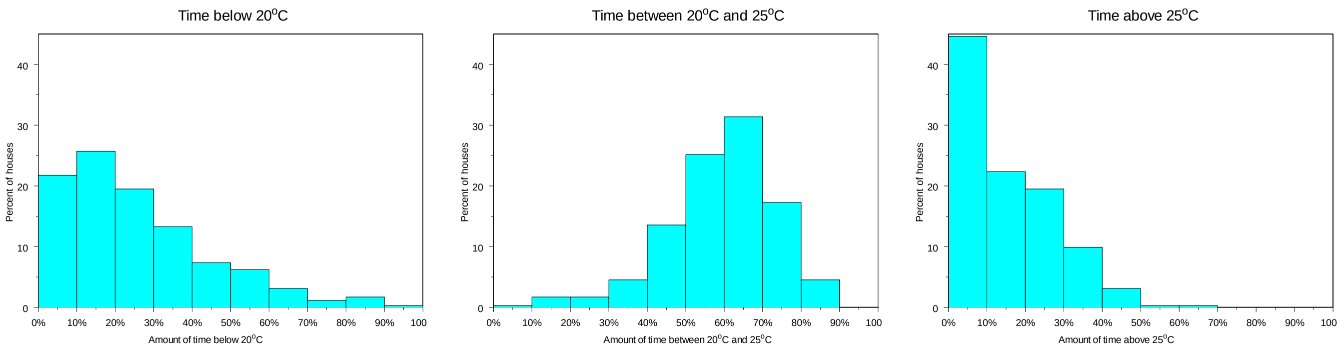


Figure 3: Time spent at given temperature range

3. INFLUENCES ON INDOOR TEMPERATURES

There are a number of possible aspects of house design, location and use that could influence living room summer temperatures. Three of these influences – climate, house age and glazing – are considered in this section.

3.1. Climate/regional differences

The differences by regional council can be seen in Figure 1. The warmer the climate, the warmer the living room temperature. For example, the median living room daytime temperature in Northland is 22.5°C compared to 19.5°C in Otago/Southland.

For each increase of 100 Degree Days, the mean house temperature decreases by 0.2°C. There is a 3.2°C difference between houses in Kaikohe (405 Degree Days) and houses in Invercargill (2025 Degree Days) for summer temperatures. Degree days have been calculated from a base of 15°C from NIWA CLIDB (Penny, 2003) using temperature data for the year the house was monitored.

3.2. House age

Newer houses are significantly warmer than older houses, as seen in Figure 4. It should be noted that the 'decade house built' is the reported decade of original construction, and that many of the older houses have been significantly modified.

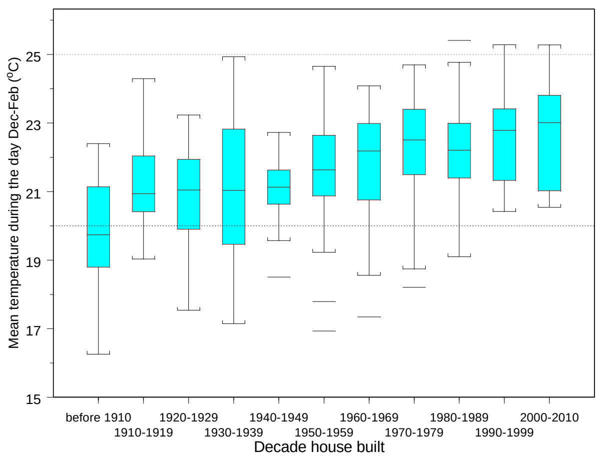


Figure 4: Summer temperatures by house age

The mean summer living room temperatures show a trend of increasing by 0.25°C per decade. This gives a difference of 2.5°C between houses built at the beginning and end of the 20th century.

The dotted lines in Figure 4 are at 20°C and 25°C to provide an indicator of the comfort envelope. One issue not explored here, but of concern, is the possible impact of higher summer temperatures due to either climate variability or climate change. As the newer houses tend already to be warmer than the older houses, their adaptation mechanisms to increased temperatures are potentially more problematic.

Houses built from 1990 onwards all have a mean daytime living room summer temperature of above 20°C, with some having a mean of above 25°C. Possible reasons for this are discussed and explored in Section 3.2.1.

House age and climate are independent of each other. Analysis showed that, on average, a group of younger houses (e.g. 20 years old) and a group of older houses (e.g. 60 years old) in two different locations (e.g. Invercargill and Auckland) will have the same temperature difference.

On examination of the difference between the living room temperature and the ambient temperature, it was found that as the house reduces in age (i.e. newer houses) there is an increase of temperature difference of 0.14°C per decade. This is not unexpected as newer houses are better insulated, but the difference is not independent of the climate. Some possible reasons for this are the varying amounts of sunshine hours through the country, solar angles, wind and precipitation.

3.2.1. Why are new houses warmer?

The analysis has shown that newer houses are warmer in both winter (Isaacs et al 2004) and summer. There are a number of reasons that could be causing this increased temperature, such as:

- airtightness – newer houses are less 'leaky'
- increased amount of glazing (see Figure 6)
- higher insulation R-values – since 1978 all new houses have had to be insulated
- larger floor area – permit trends are showing an increasing floor area
- possibly better orientation of windows for passive solar heating (although no clear indication of this can be found in the HEEP sample)
- lower ceiling levels leading to lower room volumes
- reduced or no eaves due to architectural trends.

Using the HEEP sample, some of these options were explored to examine their impact on summer temperatures.

HEEP does not undertake any control of house use. The air changes in any given HEEP house are a result of the particular occupants, their lifestyle and the local climate. A rating of each house's airtightness was recorded during the HEEP occupant survey. Four options were provided, ranging from 'airtight' to 'draughty'. As this is a self-reported rating the accuracy is unknown, as is the consistency between houses.

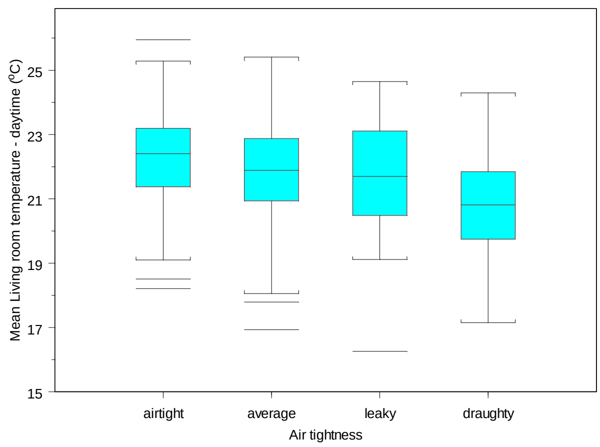


Figure 5: Mean living room temperature by airtightness

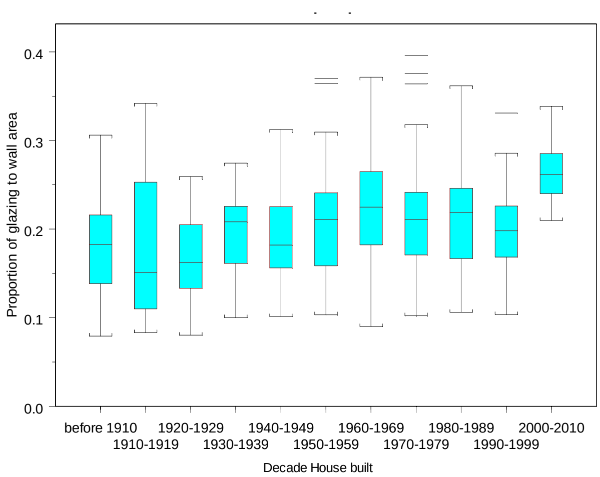


Figure 6: Proportion of glazing compared to wall area by the decade house built

The reported airtightness is plotted against mean living room daytime temperature in Figure 5. The analysis found that the influence of the reported airtightness is marginal. Occupants can readily alter the ventilation rate by opening or closing windows and doors. There are likely to be many influences on how the occupants operate their windows during the time of monitoring. This makes it impossible to accurately determine the air changes per hour for any given house. Analysis also shows that there is no obvious influence from size of the floor area on the mean living room daytime temperature.

The proportion of glazing to floor area also increases with the age of the house, as shown in Figure 6. There is more than just glazing influencing the increasing temperatures. There is a large increase in the amount of glazing in the houses built from 2000 onwards which can not be seen in temperatures. There is no increasing trend in glazing for the years 1950s to 1990s, yet temperatures are increasing during this time.

Although it is not easy to determine house component (roof, wall, floor) R-values, post-1978 houses were required to be insulated. There is no significant increase in summer daytime temperatures between pre- and post-1978 houses. This suggests that there is more than just the difference in the levels of thermal insulation in older and newer houses that affect the summer living room daytime temperatures.

3.3. Solar glazing

Jaques (2000) showed that as the proportion of glazing to floor area increased, the summer indoor temperatures also increase. The following equation was used by Jaques (2000) to establish 3pm temperatures in a typical house in Wellington, New Zealand. Using this equation, Jaques was able to modify the proportion of glazing to floor area and the amount of mass in the house to explore the impact on temperatures. All other elements of the building were kept consistent.

$$T_{\max} = T_{set} + \frac{(Q_{sol} \times A_{sol} + Q_{\text{int}}) - (T_{set} - T_{out}) \times UA \times t}{mCp + (UA \times \frac{t}{2})}$$

Equation 1: T_{max} equation based on the Los Alamos Approach (Jaques 2000)

Where:

T_{max} = maximum interior temperature (at 3pm in [^{o}C])
T_{out} = average outdoor temperature over the period examined [^{o}C]
T_{set} = interior set point temperature, at start of warm-up [^{o}C]
mCp = effective diurnal heat capacity [Wh/^{o}C]
UA = building heat loss coefficient [W^{o}C]
T = time interval of energy balance (hours)
Q_{sol} = transmitted solar heat gain per m^2 of solar glazing [kWh/m^2]
Q_{int} = internal heat gain in period examined [kWh]
A_{sol} = solar glazing area [m^2] (west, north and east glazing only).

Jaques produced a graph of the 3pm temperatures this typical house could expect with varying mass and solar glazing (west, north and east glazing only). These values are plotted in Figure 7 – the high mass house is the lower dotted line and the low mass house the higher line. Most New Zealand houses would be considered low mass, so would be expected to be closer to the higher line i.e. the summer daytime temperatures would range from 25^{o}C to above 40^{o}C for houses with 0.05 to 0.25 solar glazing area to floor area.

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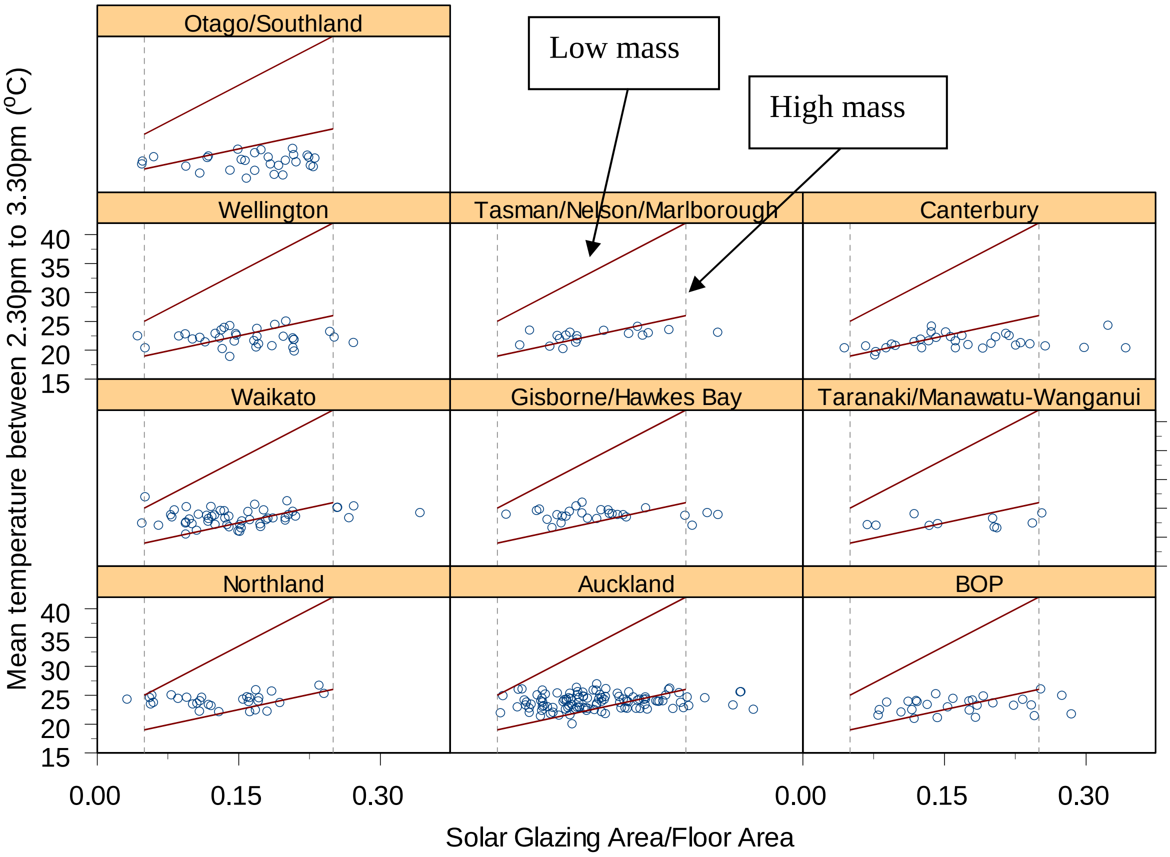

Figure 7: Solar glazing area and indoor summer temperature (at 3pm) by regional council

The data points on Figure 7 are how the HEEP houses actually behave. The area of solar glazing appears to explain very little in terms of the summer daytime living room temperature. The 3pm temperatures were used in Equation 1 and the mean temperatures between 2.30pm and 3.30pm were used in Figure 7. Using the maximum summer living room temperature does correlate slightly better than the temperatures used in Figure 7, but the difference is not significant. If the maximum temperatures are being reached while the occupants are away, this could be an indication of how much the occupants are affecting the temperatures reached in their homes by controlling factors such as:

- air changes per hour
- operation of curtains/blinds – shading.

Figure 7 shows solar glazing divided by the floor area. The ratio of the solar glazing to wall area was also examined, but there is no significant difference. The floor area to glazing ratio ranged from 3% to 34%, while the glazing to wall area ratio ranged from 2% to 35%.

	3pm	Maximum
Lowest (°C)	17.3	22.5
Highest (°C)	26.9	39.2

Table 3: Temperature range at 3pm and overall houses maximum temperatures

Although the 3pm temperature is used in Equation 1, this is not necessarily the daily maximum temperature. The range of temperatures at 3pm and the maximum temperatures for all the houses over the summer period is given in Table 3.

3.4. Conclusions

Equation 2 can be used to predict mean summer living room daytime temperatures using the house age and the local Degree Days. Linear modelling found that these two variables account for just over half (r^2 = 0.51) of the summer temperature variations. This equation is for the mean temperature over December, January and February for between 9am and 5pm.

$$SummerLivingRoomTemperature = -15.05 + YearBuilt \times 0.0201 - DegreeDays \times 0.0026$$

Equation 2: Model predicting mean summer living room temperature

Where:

$YearBuilt$ = the year the house was built e.g. 1987

$DegreeDays$ = the Degree Days used have a base of 15°C and were calculated from the NIWA CLIDB (Penny, A.C) with data from the year that the house was monitored.

As Jaques (2000) concluded, there are other influences outside of climate and glazing size that are affecting the indoor temperature. It is not possible to rate all these influences in order of importance at this stage, but with further work this will be undertaken.

4. DISCUSSION

The analysis reported here has shown that house age (represented by decade of construction) and the local climate (represented by Degree Days) have the largest impacts on the summer daytime living room temperatures.

Occupant influence also looks to be significant, but has not been quantified. Thermal calculation shows that houses behave differently without occupant influences e.g. opening and closing windows. This paper has shown that the HEEP monitored houses do not appear to follow the same trend in temperatures as demonstrated by the thermal calculation.

Occupant influence is one important difference when comparing reality with the thermal calculation used in Section 3.3. It is also important to note that the HEEP houses are all different in terms of:

- varying house size
- varying insulation
- varying occupant influence
- varying wind and ventilation due to openings
- varying locations
- shading
- orientation
- internal gains.

Further analysis will be undertaken to better understand the summer temperature performance of the monitored HEEP houses. It is expected that this will help to quantify the occupant influence.

Although climate change is not a focus of this paper, the local climate clearly influences the interior temperature. New houses are already warmer than older houses, so a 2-3°C temperature rise, possibly due to climate change, could make many of the newer houses uncomfortably warm. This problem is amplified with the houses that are being built today being 2.5°C warmer than houses built a century ago. There is the danger that the occupants of these newer houses could become reliant on air-conditioning, with the resulting higher energy use forming a positive feedback loop into the mechanism of climate change. This is clearly an undesirable result.

5. ACKNOWLEDGEMENTS

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