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Exploration of Summer Temperatures in New Zealand Houses and the Temperature Drivers

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Abstract

The Household Energy End-use Project (HEEP) has collected energy and temperature data on 397 randomly selected houses throughout New Zealand, providing a statistically representative national sample. This database has been used to explore the drivers of summer indoor temperatures.

The general lack of air-conditioning means that summer temperatures are affected by passive influences (e.g. house design, construction) compared to winter temperatures where space heating is used. Summer temperatures are strongly influenced by the house age and the local climate – together these variables explain 69% of the variation in daytime (9 am to 5 pm) living room temperatures. Newer houses tend to have larger glazing areas, higher levels of thermal insulation and reduced eaves.

Preliminary analysis suggests that as newer houses are warmer, climate change may be more important than in older houses. Human actions such as the opening of windows may have a large effect on the maximum temperature.

Introduction

The Household Energy End-use Project (HEEP) has collected temperatures from living rooms and bedrooms in 397 houses, a statistically representative sample of New Zealand. Annual reports have provided preliminary results through the project (e.g. Isaacs et al 2005).[1] Both fuel usage and temperatures were monitored for a year in each house. Temperature data and survey data collected on the house and occupants have been used in this paper to explore the summer temperatures in New Zealand houses.

HEEP monitoring of random houses began in 1999 and was completed early 2005 (see Figure 2 for locations). Limited funds restricted monitoring to fuels (electricity, LPG, natural gas, solid fuel, oil and solar hot water heaters) and temperatures. During

[1] For the latest report see www.branz.co.nz/main.php?page=HEEP

installation information was collected on the house, appliances and the hot water system, as well as the occupants (Isaacs et al 2002). Relative humidity, surface temperatures and occupant perception of comfort were not measured in HEEP.

Figure 1: HEEP temperature loggers

HEEP recorded air temperatures 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 away from heating sources. The data is downloaded monthly and checked thoroughly to remove any inaccuracies. Monitoring of each house is carried out for a period of approximately one year. Temperature measurements were carried out with two types of loggers (Figure 1): a purpose designed BRANZ temperature logger with an uncertainty of 0.2°C and the 'Tinytag' with an uncertainty of 0.3°C. At the start of each monitoring period, the BRANZ temperature loggers were calibrated in a thermal environment with direct traceability to the New Zealand standard temperature reference (see Pollard 2001).

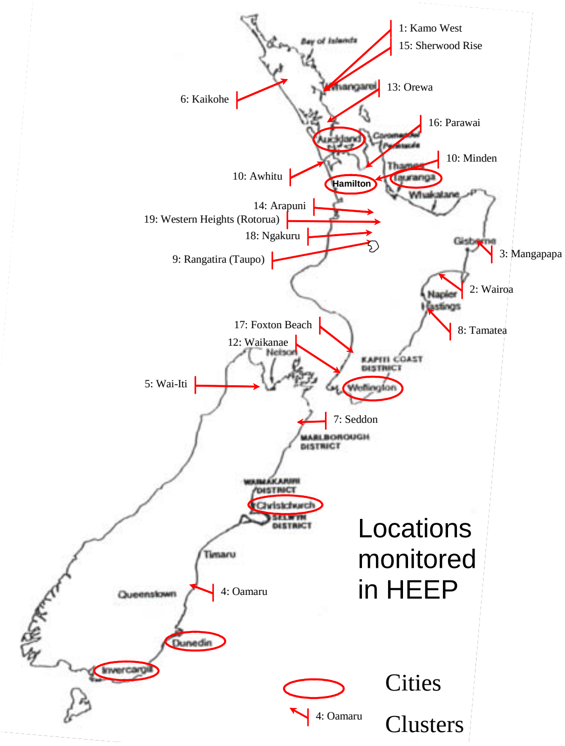

Figure 2: HEEP monitoring locations

The summer months in New Zealand (a Southern Hemisphere country) are December, January and February.

January and February, with approximately the same mean air temperature, are the warmest months.

The country is long and narrow, approximately 1,600 km in length, with a land area of 270,000 sq km, ranging from Latitude 37°S to 46°S (Statistics New Zealand 2005).

The average summer ambient 24 hour temperature in Kaikohe (far north) is 18.8°C, but in Invercargill (far south) only 13.3°C – a difference of 5.5°C. These locations and other HEEP monitoring locations are shown on a map of New Zealand in Figure 2.

Nicol and Humphreys (2002) and Brager and de Dear (1998) suggest that an acceptable internal temperature depends on the external temperature as occupants adapt to the external climate (adaptive temperatures). There is no New Zealand research on how the ambient temperature affects their perception of comfort inside houses or offices.

Given the constraints of the data, it has been necessary to establish a suitable comfort range. Camilleri (2000) and Jaques (2000) used 20°C to 25°C for New Zealand summer conditions, while Donn and Thomas (2001) used 16°C to 26°C to deal with winter and summer. For the purposes of this paper the range of 20°C to 25°C has been used to represent comfort temperatures.

Summer temperature distribution

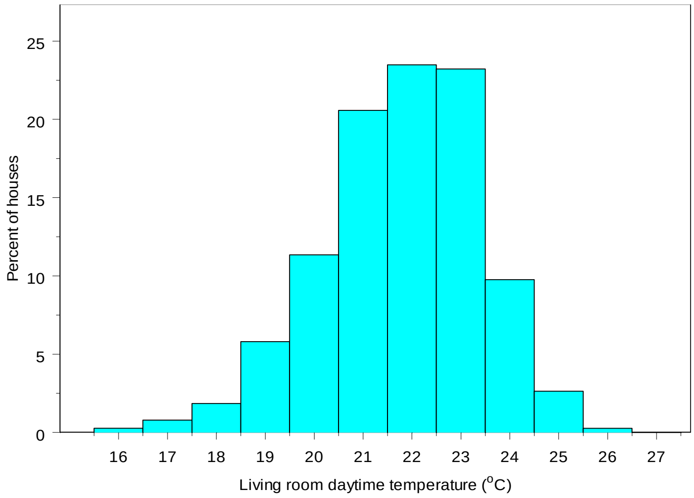

Figure 3: Mean living room temperatures

Few New Zealand houses are heated or cooled during the summer months. The monitoring found that 4% of households in the HEEP sample have air-conditioners or reverse cycle heat pumps. To complicate the issue, 3% of the HEEP houses heat throughout the whole year, although these tend to be in the cooler southern parts of the country.

Figure 3 shows the distribution of living room mean daytime (9 am to 5 pm) temperatures over the summer months for all HEEP houses throughout New Zealand. Eighty-five percent of the houses have a mean living daytime temperature between 20°C and 25°C, while less than 1% are over 25°C and just over 14% are under 20°C. HEEP analysis has found that the average mean daytime living room summer temperature is 21.8°C, the maximum mean temperature is 25.9°C and the lowest mean temperature is 16.3°C.

Figure 4 shows the distribution of the proportion of time between 9 am and 5 pm 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. However, 1% spend over 50% (four hours per day) of the summer daytime above 25°C. This 1% can be considered to be at uncomfortably high temperatures for over half the day.

Over all the houses, the majority (80%) spend less than 25% of the summer daytime (two hours per day) at temperatures over 25°C. The majority of the houses are between 20°C and 25°C for the majority of the time. As we have not collected data on the occupants' perception of comfort or other climatic factors such as air changes per hour, humidity and clothing levels, it is not possible to definitively conclude that these are comfortable temperatures. However, these would be considered comfortable based on the overseas definitions.

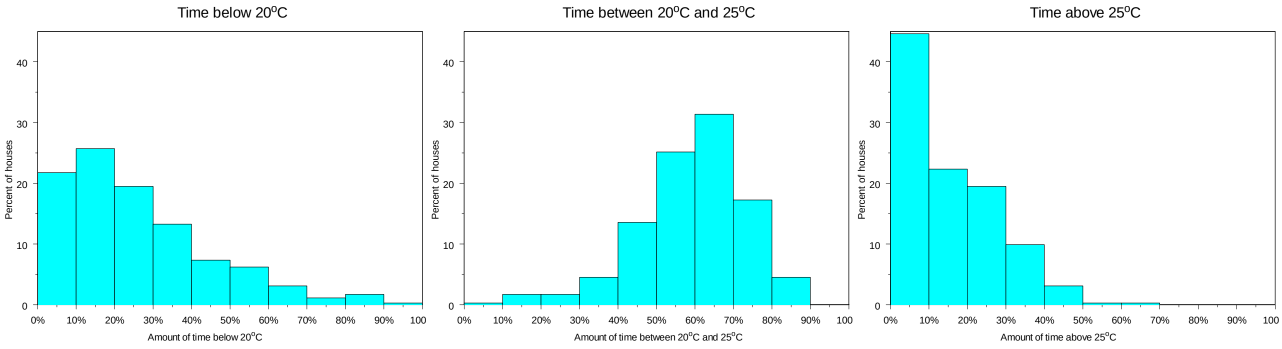

Figure 4: Time spent at given temperature ranges

Table 1 gives the mean temperatures for four different periods of the day for the ambient external temperature, the bedroom and the living room. Table 1 shows the bedroom is always slightly cooler than the living room. Analysis of the HEEP houses has found that New Zealand houses have randomly orientated windows (on average about 25% of the total glazing is in each compass direction) with living rooms also being randomly orientated. This may explain the small temperature difference between living rooms and bedrooms, as neither can be guaranteed to benefit from the sun.

The periods when the bedroom temperature is closest to the living room temperature are the night (midnight to 7 am) and the morning (7 am to 9 am) – these are times when the bedroom is likely to be occupied and therefore have internal heat gains (from televisions, clock radios, cats, dogs and humans). The bedroom also has less of a decrease from evening to night than the living room, again likely to be caused by the internal gains.

The moderating effect of the house can be seen in the 4°C mean temperature range for the internal spaces (from 19.1°C to 23.1°C) which is not as large as the 5.6°C ambient temperature range (from 14.5°C to 20.1°C). Houses with high levels of thermal mass (which will have a stabilising effect on temperatures e.g. concrete or double wall brick – see Donn and Thomas 2001) would be expected to have a lower temperature range. However, this could not be confirmed as there are only two such houses in the sample. Most New Zealand houses are timber frame with an external veneer and are considered to be low thermal mass.

Table 1: Mean temperature during time periods

	Mean temperatures for all houses			
	Morning 7 am to 9 am	**Day 9 am to 5 pm**	**Evening 5 pm to 11 pm**	**Night Midnight to 7 am**
Living room (°C)	19.2	21.8	23.1	20.3
Bedroom (°C)	19.1	21.2	22.6	20.1
Ambient (°C)	15.8	20.1	17.9	14.5

This distribution of living room and bedroom temperatures and the shift between morning and daytime is shown in Figure 5. The living room temperature distributions are shown in the two graphs on the left and the bedroom temperature distributions are shown with the two graphs on the right. The top two graphs show the distribution of morning temperatures and the lower two show daytime temperatures.

The range of temperatures for both the bedroom and the living room during the morning is approximately 14°C to 24°C with a mean of 19°C. During the daytime the temperatures range from 16°C to 26°C and means of 21°C for both the bedroom and the living room – an increase in both the range and the mean of 2°C from the morning (shown by the dotted line and arrow on Figure 5).

The shapes of both the morning temperature distribution histograms for the living room and bedroom are similar; with the bedroom mean 19.1°C and the living room 19.2°C.

The temperature range for bedrooms is slightly lower than for living rooms, but the overall shape is very similar, with the day means of 21.1°C for the bedroom and 21.8°C for the living room.

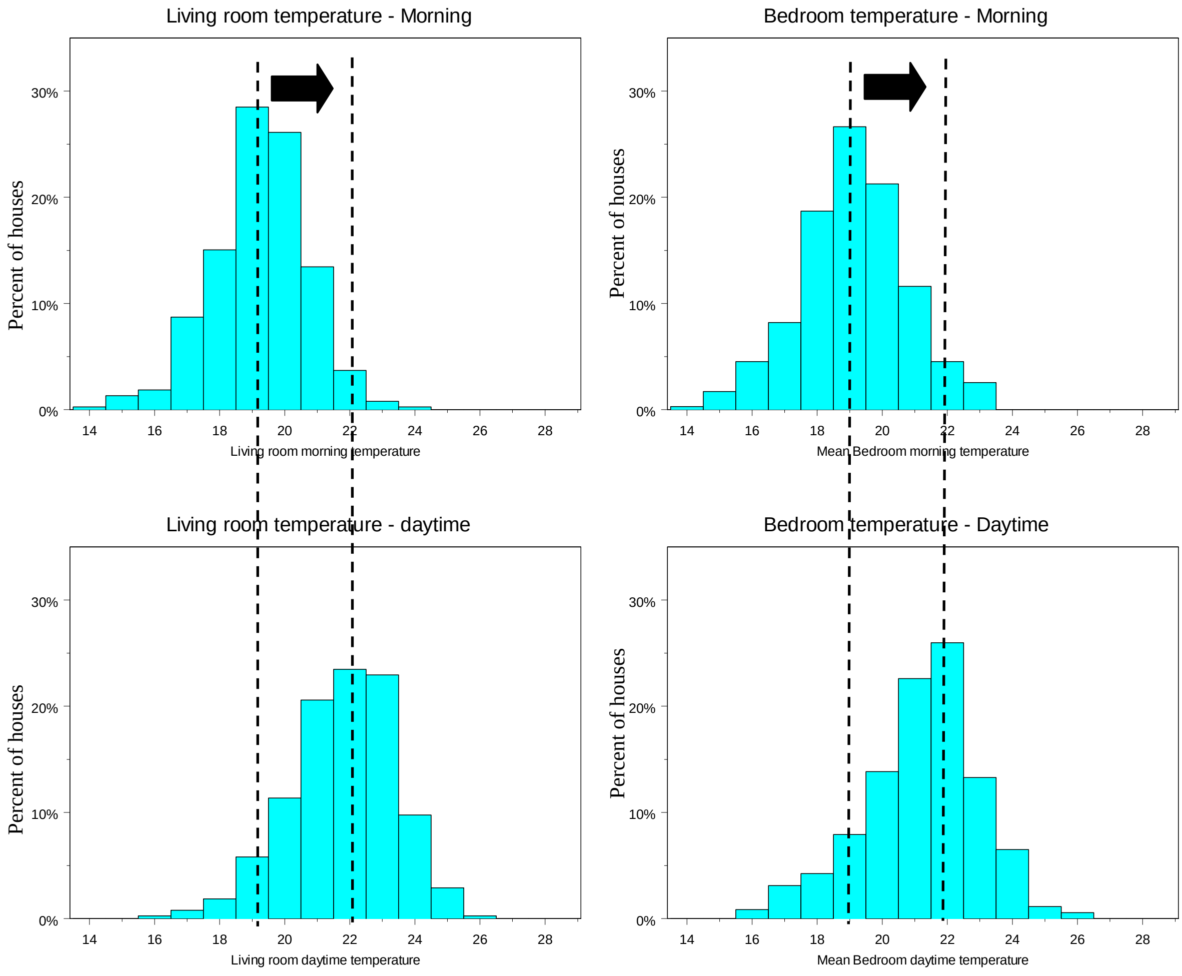

Figure 5: Living and bedroom temperature distribution for morning and day

Maximum temperatures

The time of day the maximum temperature is reached and the living room maximum temperature distribution are plotted in Figure 6 and Figure 7.

The temperatures reported here are the maximum temperatures reached in the three months of summer. Data from 14 houses (3.5%) was removed from the analysed sample due to the maximum temperature being recorded when the house was being heated – often late at night – at times with the use of a solid fuel heater (producing hot water) resulting in temperatures above 40°C! However, in other houses lacking the use of the solid fuel burner to heat water, there is no obvious reason why living rooms should be heated to such high temperatures during the summer.

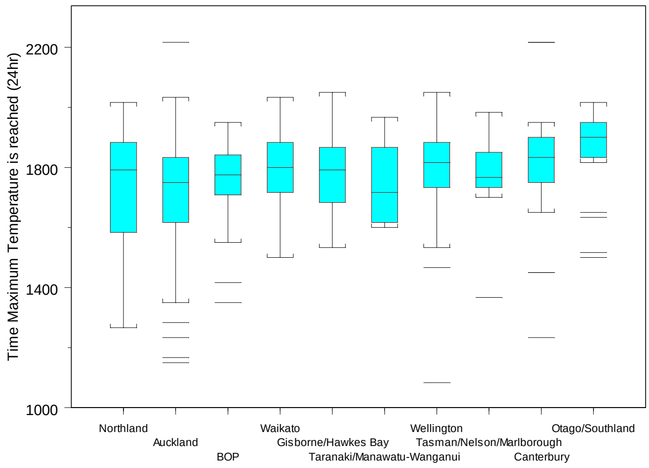

Figure 6: Time of maximum living room temperature by Regional Council

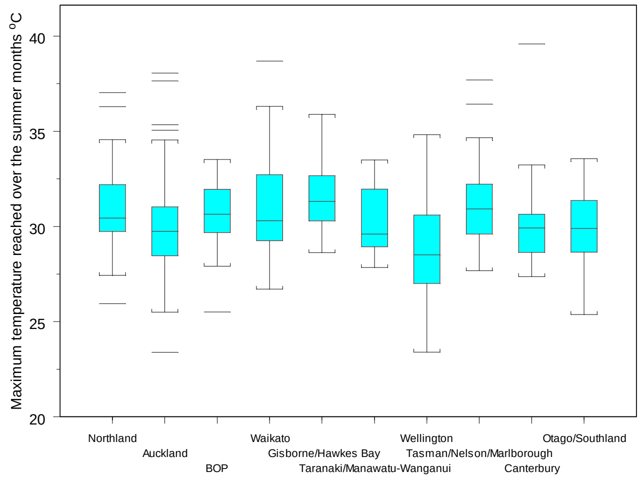

Figure 7: Maximum living room temperature by Regional Council

On average, the maximum temperature in the living room is reached at 5.40 pm, although the time of day varies by region (as seen in Figure 6).

Auckland (in the north) has a mean time of maximum temperature of just after 5 pm and the Otago/Southland region has a mean time of 6.40 pm. The sunset at the start of January varies from 7.43 pm in Auckland (36° 52' S 174° 45' E) to 8.42 pm in Invercargill (46° 25' S 168° 21' E). Although there are still outliers, the range of times is closer the further south the region.

The distribution of the maximum summer temperatures is plotted in Figure 7 by region. This variation is not a simple north to south variation, but clearly depends on other factors which may include:

- **regional geography** – both Wellington and Dunedin are hilly with some houses getting little or no direct sun inside the house. Large variations in temperatures can be seen in these regions
- **sun angles, sunrise and sunset times** – the sun sets later in the south than the north and rises earlier in the north compared to the south
- **house variations** – age (proportion of older/newer houses), window sizes and orientation, construction and shading devices, etc
- **sunshine hours** – these vary throughout the country with the upper South Island (Tasman/Nelson/Marlborough) having the highest sunshine hours, followed by the east coast of the North Island (East Coast/Hawkes Bay). Of the HEEP locations, Dunedin has the lowest sunshine hours with Invercargill next – both of these locations are in Otago/Southland region (NIWA 2006).

Influences on indoor temperatures

The main drivers of summer living room daytime temperature have been found to be the climate and the house age.

Climate/regional differences

The differences in mean daytime living room temperature by Regional Council can be seen in Figure 8 (the black squares show the mean ambient daytime temperature for the region). It is clear that 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 (3°C difference).

Figure 8 shows the mean daytime (9 am to 5 pm) temperatures over the summer months for HEEP houses throughout New Zealand. The houses are grouped by Regional Council or groups of these councils when there are small numbers of monitored houses in their regions. The graph is ordered from the north to the south (left to right); this shows how the warmer climate in the north affects the interior temperature compared to the colder southern climate.

Figure 8 shows that the mean daytime summer ambient temperatures are similar in the southern-most region of the North Island (Wellington) and the northern-most regions in the South Island (Tasman/Nelson/Marlborough). This is at least in part a function of geography – both Nelson and Wellington are at 41°S (see Figure 2).

The means of the daytime living room mean temperatures shown in Figure 8 range from about 20°C to about 23°C, apart from Otago/Southland with a mean of 16°C.

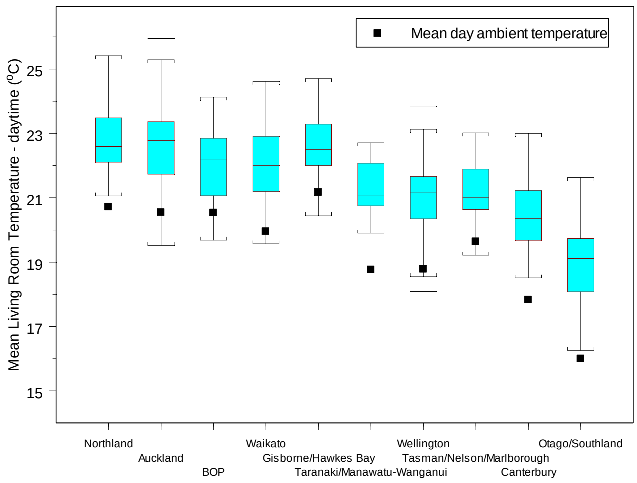

Figure 8: Mean living room daytime temperatures by Regional Council

Analysis of the data shows that for each increase of 1°C for the average external temperature,[2] the mean house temperature increases by 0.81°C. There is a 4.5°C difference between houses in Kaikohe (18.8°C mean external temperature) and houses in Invercargill (13.4°C mean external temperature) for summer daytime temperatures. Using climate alone this accounts for 68% of the variance ($r^2 = 0.68$, p-value = 0.0000).

[2] Average external temperatures were calculated using NIWA CLIDB temperatures for the year the house was monitored.

House age

Newer houses are warmer than older houses (as seen in Figure 9). This difference is statistically significant (p-value 0.0000). 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.

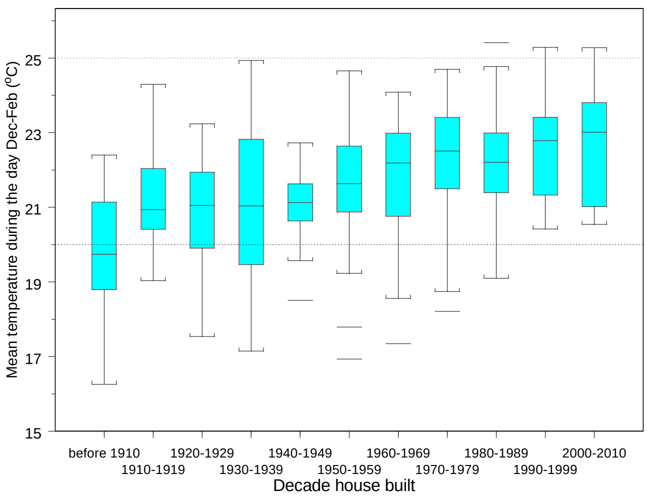

Figure 9: Summer temperatures by house age

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

The dotted lines in Figure 9 are at 20^{o}C and 25^{o}C. Apart from the pre-1910 houses, the mean temperatures for all house ages are within this range. Houses built from 1990 onwards all have a mean daytime living room summer temperature of above 20^{o}C, but the average temperature in this group is close to 23°C with extreme means above 25^{o}C.

Examination of the difference between the living room temperature during the day and the ambient temperature found that as the house reduces in age (i.e. newer houses) there is an increase in the inside-to-outside temperature difference of 0.22^{o}C per decade. This is not unexpected as newer houses are better insulated. There is also a climatic driver in this temperature difference, but together the two only account for 11% of the variance ($r^2 = 0.11$, p-value = 0.0000).

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. Air-conditioners in New Zealand are becoming more and more popular, with one supplier reporting increases in sales of up to 35% a year (Ninness 2006). If they are used to reduce high summer temperatures, this will have undesired impacts on the electricity system.

Model of summer living room temperatures

The analysis has been used to develop a simple model of summer temperatures. Equation 1 links the Average External temperature for the summer months and the house age to model the expected summer daytime mean temperatures. Linear modelling found that these two variables account for (r^2 = 0.69) of the summer temperature variations (p-value = 0). This equation is for the mean temperature over December, January and February for between 9 am and 5 pm.

$$SummerLivingRoomTemp. = -12.62 + YearBuilt \times 0.009 - AveExtTemp \times 0.76$$

Equation 1

Where:
YearBuilt = year the house was built e.g. 1987
AveExtTemp = average external temperature for the months of December, January and February for the year that the house was monitored

Separate testing has found that the house age and climate are independent of each other.

Using these two variables (house age and external mean temperature) for other times of the day (e.g. morning, evening and night) explain 60–69% of the variation, and explain 74% of the variation for a 24 hour mean temperature.

The house age without the average external temperature explains 14% of the variation in daytime living room temperatures.

Why are new houses warmer?

HEEP analysis has already 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, such as:

- **higher insulation R-values** – since 1978 all new houses have had to be insulated
- **airtightness** – newer houses are less 'leaky'
- **increased glazing area** – a possible trend to increased use of glass
- **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** heights 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.

Thermal insulation

Although it is not easy to determine house component (roof, wall, floor) R-values, post-1978 houses were required to be insulated. Although there is a significant increase in wintertime temperatures (see French et al 2006), 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.

Orme and Parker (2003) found that highly insulated UK buildings had a high chance of summertime overheating if measures are not taken to control the solar and internal gains. Orme and Parker suggested measures including night cooling, external shading, ventilation, reducing internal gains and providing thermal mass. Although Orme and Parker suggested and explored (by modelling) methods of reducing the solar and internal gains, they could not conclude that insulation was the cause of the high temperatures in summer.

Airtightness

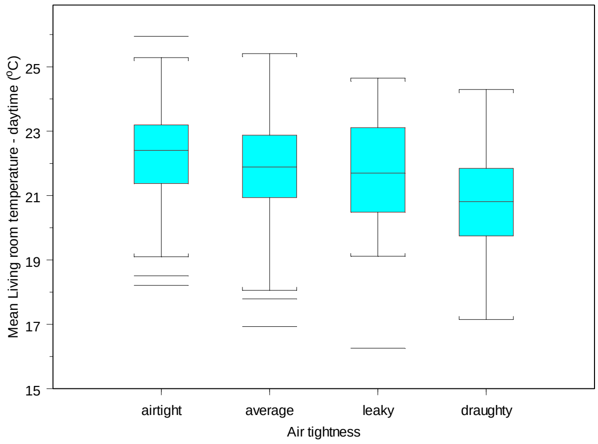

Figure 10: Mean living room temperature by airtightness

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.

The reported airtightness is plotted against mean living room daytime temperature in Figure 10. The analysis found that the influence of the reported airtightness is marginal.

Occupants can easily alter the ventilation rate by opening or closing windows and doors. As there are many influences on the window operation, it is impossible to accurately predict the air changes per hour for any given house.

Glazing and floor area

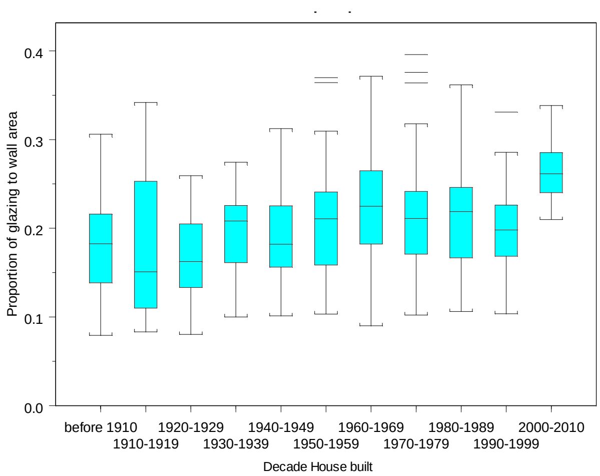

Figure 11: Glazing to wall area ratio by decade house built

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 11). 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 (see Figure 9).

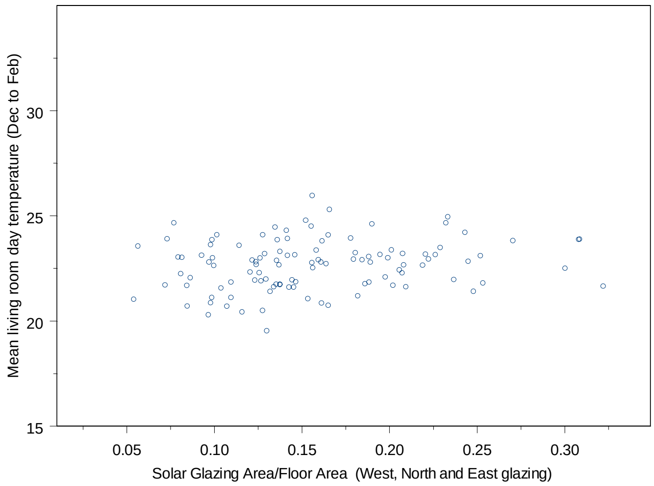

Figure 12: Solar glazing ratio vs Auckland living room temperatures

Solar glazing (west, north and east facing glazing) has been looked at separately, but there is no obvious relationship between large solar glazing areas and high temperatures.

Figure 12 shows an example of preliminary work with the solar glazing area as a proportion to floor area on the x-axis and the mean daytime living room temperature on the y-axis. This graph plots just the 114 houses in the Auckland area, so all the houses have a similar climate.

The expected pattern would be that the higher the ratio of the solar glazing area to the floor area, the higher the living room temperatures. This is not the case in Figure 12.

The data has been explored regionally, using average and maximum temperatures achieved at different periods of the day. Orientation of the living room, the amount of shading, sunshine hours and the glazing in both the proportion to floor and wall area are just some of the possible influences that have been explored. However, each has shown very little difference to the overall 'flat' pattern of temperatures as shown in Figure 12.

One issue that remains to be explored through modelling is the influence of occupants. It may be possible that through the control of windows or fans (ventilation), and the control of shading, occupants have been able to limit the temperatures reached in their houses.

Discussion

This paper has taken temperature data collected as part of a large energy study and examined them in summer. As few New Zealand houses are cooled (air-conditioned) during the summer, this represents a large sample of naturally ventilated houses, with the ventilation controlled by the occupants' use of windows and doors.

The majority of houses (80%) spend less than one quarter (25% – two hours) of the summer daytime with living room temperatures over 25°C. Most living rooms are between 20°C and 25°C for the majority of the time. As there is no analysis of 'comfort' temperatures for New Zealand, it can only be concluded that based on overseas norms these would appear to be comfortable.

On average, bedroom temperatures are lower than living room temperatures – by as little as 0.1°C in the morning (7 am to 9 am) and as much as 0.6°C during the day (9 am to 5 pm). Inside temperatures have a smaller temperature range than the ambient, showing the temperature stabilising benefit of even low thermal mass construction.

Maximum temperatures are not only driven by solar radiation. The use of solid fuel burners led to indoor summer temperatures above 40°C in some houses. Excluding such houses, the maximum temperature is reached by 5.40 pm, although regional variation ranges from 5 pm (Auckland in the north) to 6.40 pm (Otago/Southland in the south). The variation is not a simple north to south issue, as other factors would appear to be involved, including house age.

The house age (represented by decade of construction) and the local climate (the average external temperature over summer) have the largest impacts on the summer daytime living room temperatures. Together they explain 69% of the variation in mean summer living room day temperatures. A simple model has been prepared based on these two variables.

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 the end of the 20th century.

Selected reasons for newer houses being warmer have been explored. The influence of occupant self-reported house airtightness has been found to be marginal, as has the presence of thermal insulation. No obvious relationship has been found between large areas of solar (west, north and east facing glazing) and high 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.

A Masters in Building Science is currently being undertaken by the lead author on overheating in recently constructed houses in New Zealand to better understand the summer temperature performance of the monitored HEEP houses. One of the expected outcomes of this will be 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 those 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.

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