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INFLUENCES ON SUMMER INDOOR TEMPERATURES IN A REPRESENTATIVE SAMPLE OF NEW ZEALAND HOUSES

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ABSTRACT

The Household Energy End-use Project (HEEP) has collected energy and temperature data from a randomly selected, nationally representative sample of 397 houses throughout New Zealand. This database has been used to explore the influences of indoor temperatures. The lack of air conditioning suggests summer temperatures are affected mainly by passive influences (e.g. house design, construction). Analysis found that summer temperatures are strongly influenced by the house age and local climate – together they explain 69% of the variation in day-time living room temperatures. Newer houses have higher temperatures (both summer and winter), a desirable effect in winter but more likely to result in summer over-heating. This paper examines the differences in design and construction of new houses that could be the underlying causes of the increasing summer temperatures. Houses have been modelled to examine the effect of temperature when physical and occupant influences are altered.

Keywords: Residential Temperatures, Summer Over-heating, Household Energy End-use Project (HEEP).

INTRODUCTION

The Household Energy End-use Project (HEEP) has monitored energy use and temperatures in a nationally representative sample of 397 randomly selected houses throughout New Zealand. Temperatures were monitored in the family room (at two different heights) and the master bedroom in every house. Temperatures were recorded at a 10 minute interval for approximately 12 months. Additional information was collected with a house audit recording the physical attributes of the house and a detailed occupant survey covering information on the occupants and how they use energy and their house. For more information on HEEP see the annual reports (Isaacs et al 2006).[1]

This paper uses the HEEP temperature measurements to explore summer temperature patterns and the influences on summer temperatures, in particular the trend of increasing temperatures in newer houses. Thermal modelling of a selection of HEEP houses has been undertaken to explore the impacts of changes in house design, construction and use.

NEW ZEALAND HOUSES

A typical house in New Zealand is timber framed with weatherboard or brick veneer cladding (75% of HEEP sample), a timber (60%) or concrete floor (30%) and a long-run steel roof (61%) or tiles (22%). Houses are typically stand-alone with one level (71%) or two levels (26%). The concrete slab floor is normally covered with carpet – 66% of houses with slab floors have carpet throughout their living areas compared to 57% of houses with suspended timber. The construction of floors has changed over the years, with concrete slab becoming more popular. Just 12% of pre-1950 houses have a slab, increasing to 40% for post-1950 and 65% for post-1978.

Year Commenced	Standard	Coverage	R-values (m^2°C/W) Ceiling	Wall	Floor
1978	NZS 4218P:1978	New Zealand	1.9	1.5	0.9
1996	NZS 4218:1996	Zones 1&2	1.9	1.5	1.3
		Zone 3	2.5	1.9	1.3

Table 1: Building Code thermal performance requirements 1978 to current

New Zealand has required thermal insulation in new houses since 1 April 1978, under the New Zealand Building Code (NZBC) Clause H1: Energy Efficiency (Standards NZ, SNZ 2004). These requirements were increased slightly for houses in the central North Island and all the South Island (Zone 3) in 1996. The other two climate zones cover the remaining area of the North Island (Zones 1&2). Table 1 sets out thermal resistance requirements for common combinations of roof, wall and floor (Isaacs 1993 and 1999). These thermal insulation requirements applied only to new houses. Older houses are not required to upgrade to the current standard, but in some cases roof and floor insulation has been voluntarily installed.

[1] HEEP annual reports can be downloaded at no charge from www.branz.co.nz.

NEW ZEALAND CLIMATE

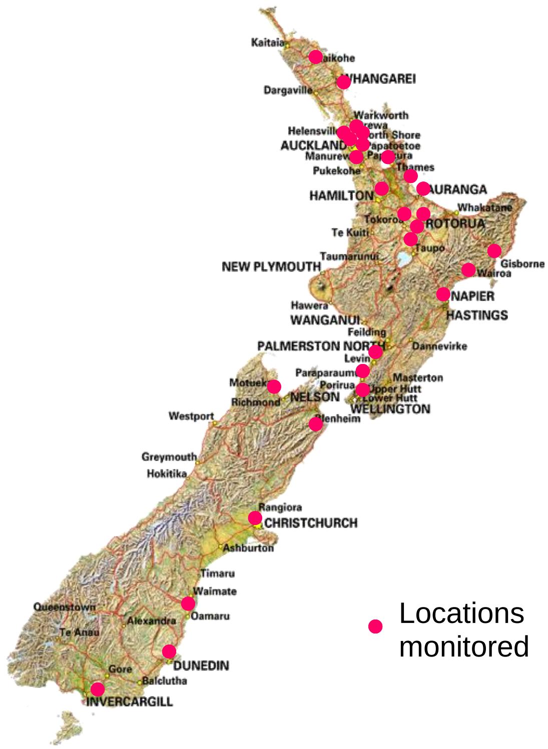

Figure 1: Map of monitored locations

New Zealand is long and narrow, approximately 1,600 km in length, with a land area of 270,000 sq km, ranging from Latitude 37^{o}S to 46^{o}S (Statistics NZ 2006).

The summer months are December, January and February. The majority of homes are in a coastal climate, but the central areas of both islands are more continental with a hot summer and cold winter.

The mean summer ambient daily temperature in Kaikohe (far north) is 18.8^{o}C, and in Invercargill (far south) 13.3^{o}C – a difference of 5.5^{o}C.

Figure 1 shows the locations HEEP monitored in New Zealand.

SUMMER CONDITIONING OF NEW ZEALAND HOUSES

Very little conditioning is done during summer, with only 4% of the HEEP houses found to be capable of cooling (through heat pumps working in reverse). A small number of houses (3%) heat throughout the whole year, but these are mainly in the southern, cooler locations. The number of houses capable of cooling has increased significantly since HEEP monitoring was completed through the widespread adoption of heat pumps. It is now estimated that approximately 11% of houses have heat pumps (Buckett 2007) but little is known about the current use of heat pumps for cooling. With an increase in indoor temperatures due to either climate change or the design of the houses an increase in cooling would also be expected if available.

Given the lack of cooling and heating during summer in the HEEP sample, it can be assumed that the indoor temperatures are influenced by the climate, occupants and the physical features of the house.

SUMMER TEMPERATURES

Both the living room and the bedroom temperatures in the HEEP houses were examined for the summer months, although the focus of this paper is the living room. The living room temperatures were examined for the evening (5 pm – 11 pm) and the bedroom overnight (midnight to 7 am). These times were chosen as the rooms are likely to be occupied. Very little work has been undertaken in New Zealand on comfort temperatures and conditions, so it was not possible to establish a comfort temperature range. In addition, although comfort is considered to strongly relate to the air temperature, it also depends on other factors such as humidity, activity levels, air speed, clothing etc, which were not able to be monitored in HEEP.

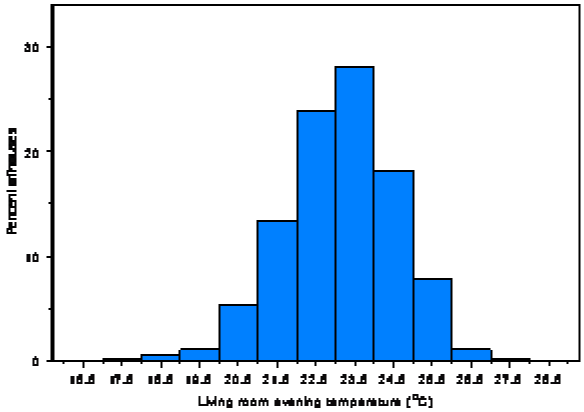

Figure 2. Living room evening summer temperature

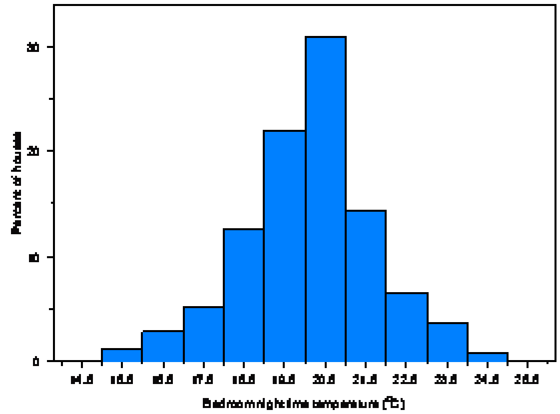

Figure 3. Bedroom night-time summer temperature

Figure 2 shows the mean living room evening and Figure 3 the mean bedroom night-time temperature distribution for all HEEP houses. Temperatures range from 17.9°C to 27.3°C in the living room with a mean of 23.1°C, and from 15.3°C to 24.5°C in the bedroom with a mean of 20.1°C. Temperatures above 25°C can be considered uncomfortably warm (Jaques 2000) and (Donn and Thomas 2001). This work looks at the causes of these high temperatures.

Previous work has found summer temperatures to be influenced by both climate and the house age (French et al 2007). The following section will examine temperatures considering these influences.

SUMMER TEMPERATURES BY CLIMATE AND HOUSE AGE

Linear modelling has found that house age and external mean temperature explain 60% to 69% of the variation in internal mean temperature, depending of the time of day (e.g. morning, day, evening and night), and explain 74% of the variation for a 24 hour mean temperature (p-value = 0). The house age alone explains 14% of the variation in day-time living room temperatures.

The mean summer living room temperatures in the HEEP houses show an increase of 0.25°C per decade of house construction. Over half of the oldest houses (pre-1910) have a mean summer day-time living room temperature below 20°C, while houses built after 1990 all have a mean summer day-time living room temperature above 20°C, with the average temperature in this group close to 23°C and extreme means above 25°C.

Examination of the summer day-time temperatures found the greatest differences are between pre- and post-1950 houses. Therefore, for this paper the HEEP houses have been divided into two groups: pre-1950 and post-1950.

The NZBC Clause H1 Acceptable Solution NZS 4218 (Standards NZ, SNZ 2003) separates New Zealand into three ‘climate zones’ for the required level of thermal insulation (see Table 1). These three zones have been used to example the effects of climate on the HEEP sample. Zone 1 is the warmest (includes Auckland, Northland and

the Coromandel), and Zone 3 the coolest (includes the South Island and the central plateau in the North Island), with Zone 2 comprising of the rest of the North Island.
Table 2 to Table 4 analysis excludes houses for which no age classification was possible.

		Living room (°C)				External (°C)				
House age	**Climate zone**	**Mean**	**SE**	**Max**	**Min**	**Mean**	**SE**	**Max**	**Min**	**Count**
Pre-1950	1	23.2	0.2	24.3	19.6	19.0	0.1	22.0	15.2	29
Post-1950	1	23.9	0.1	25.3	19.6	19.1	0.1	22.2	15.4	111
Pre-1950	2	22.5	0.3	23.2	18.5	18.3	0.1	22.1	12.3	27
Post-1950	2	23.5	0.1	24.8	19.0	18.4	0.1	22.2	12.9	104
Pre-1950	3	21.1	0.3	22.4	16.7	15.7	0.2	19.5	10.6	24
Post-1950	3	22.3	0.2	23.5	17.8	16.0	0.1	19.7	11.2	60

Table 2: Living room and external evening temperatures by house age

Table 2 shows an increase in mean evening temperature between the pre-1950 and post-1950 houses of between 0.7°C and 1.2°C, depending on the climate zone. The colder the climate zone the greater the difference between pre-1950 and post-1950 houses. ANOVA tests show that the differences between the climate zones and house age is significant at the 95% level for the living room temperatures. The difference between climate zones is also significant at the 95% level for external temperatures.

House age	Climate zone	Time < 20°C (%)	SE	Time 20–25°C (%)	SE	Time >25°C (%)	SE	Count of houses
Pre-1950	1	8	1.5	70	3.4	22	3.7	29
Post-1950	1	4	0.5	65	1.5	31	1.6	111
Pre-1950	2	18	3.4	65	2.9	17	2.9	22
Post-1950	2	9	0.9	62	1.4	29	1.7	101
Pre-1950	3	34	4.0	58	3.4	8	1.6	24
Post-1950	3	19	2.1	65	1.7	17	1.8	59

Table 3: Percent of hours in specified temperature ranges during evenings in living rooms during summer

Table 3 gives the percentage of average hours during the evening in three specified temperature ranges for pre-1950 and post-1950 houses in the three climate zones. In all three climate zones there is a higher proportion of time spent above 25°C for the post-1950 houses and less time below 20°C. In Zone 3 the amount of time over 25°C is more than double (17%) than in the post-1950 houses (8%). ANOVA tests show differences between both climate and pre-1950 and post-1950 houses for time below 20°C and time above 25°C which are statistically significant at the 95% level.

House age	Climate zone	Temperature range °C		Count of Houses
		Living room	External	
Pre-1950	1	4.7	6.8	29
Post-1950	1	5.7	6.8	111
Pre-1950	2	4.7	9.8	22
Post-1950	2	5.8	9.3	101
Pre-1950	3	5.7	8.9	24
Post-1950	3	5.7	8.5	59

Table 4: Mean 24 hour temperature range by house age and climate zone

Table 4 gives the mean diurnal range over 24 hours for the summer period. For both Zone 1 and 2 the range is larger for the newer houses, but in Zone 3 there is no difference. As discussed, a higher proportion of newer houses have concrete slab floors and hence higher thermal mass. The diurnal range would be expected to decrease in these higher mass, newer houses but this is not the case in two of the three climate zones. The reasons for this are not yet clear. Two possible reasons include not enough usable mass to regulate the temperature, and increasing amounts of windows and solar access which increase solar gains during the day and increase heat losses during the night.

Table 2 gives the mean daily maximum and minimum temperatures for the living room and external temperatures by house age and climate zone over the three summer months. The post-1950 houses have higher or the same average maximums showing the increase in diurnal range is due to higher temperatures.

DIFFERENCES IN NEW HOUSES

The following gives information on some of the changes that have been found in newer houses and which are possibly contributing to the higher temperatures. Given the changes that have occurred, it is not always possible to compare a sample of older and newer houses to explore the effect of a specific change on temperatures.

INSULATION

Since 1 April 1978 post-1978 houses are required to have insulation, allowing comparisons to be made with pre-1978 houses, although some pre-1978 houses have been retrofitted (partially or fully). Comparisons done between pre- and post-1978 living room temperatures showed a marginal difference (French et al 2006).

GLAZING

House age	Climate zone	Solar glazing/ solar wall area (%)	SE	Count of houses
Pre-1950	1	23.9	2.7	30
Post-1950	1	27.4	1.4	112
Pre-1950	2	24.1	2.0	27
Post-1950	2	28.3	1.3	105
Pre-1950	3	27.0	3.8	24
Post-1950	3	30.5	1.8	58

Table 5: Solar glazing as a percent of solar wall area by climate and house age

Table 5 gives the solar glazing area (east, north and south glazing) as a percentage of wall area. The larger the glazing area means not only more solar gains during the day heating the space, but more losses at night. For all three climate zones the post-1950 houses have a larger percentage of glazing area. The differences between the groups are significant (p-value: 0.045).

ORIENTATION

	Pre-1950	Post-1950
N, NE, NW	47%	59%
S, SE, SW	31%	22%
W	12%	13%
E	9.5%	6.4%
Count of Houses	74	266

Table 6: Living room orientation

Table 6 gives the living room orientation by house age. Houses with two living rooms in different directions have been removed from the analysis in Table 6. North, north-east and north-west are the most common orientation for both pre-1950 and post-1950 houses. However, north orientations are more common in the post-1950 houses – northern orientation allows greater day-time solar gains. There has conversely been a reduction in the proportion of south, south-east and south-west facing living rooms. The proportion of west and east facing rooms has stayed similar over time.

AIRTIGHTNESS

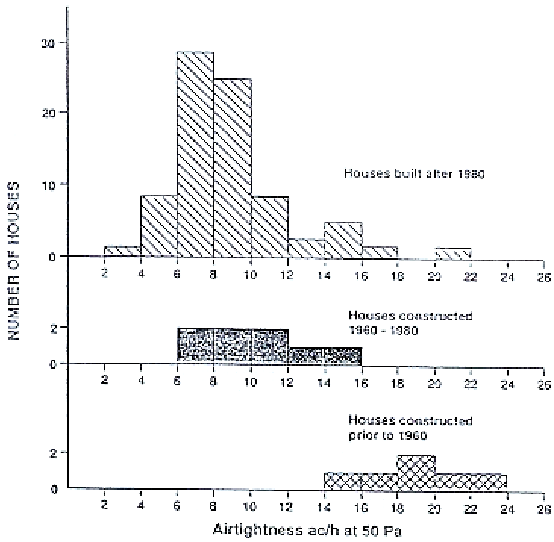

Figure 2: Histogram of air change rates at 50 Pa for 40 New Zealand houses (Bassett 1992)

Having an airtight house means less heat losses in winter, but could be contributing to higher summer temperatures. Ideally houses should have the ability to control ventilation when needed e.g. opening windows that are not a security risk or allow unwanted noise inside.

Airtightness was not measured in the HEEP houses due to the expense in both time and money. Instead occupants were asked their opinion as to the house airtightness. The occupant-reported airtightness was found to have a marginal influence on summer temperatures (French et al 2006), although the quality of this reported airtightness cannot be quantified.

Previous work by Bassett (1992) found a correlation between house age and airtightness (Figure 4). Newer houses (post-1980) were, on average, more airtight although the range of airtightness is large. It should be noted that the reported air changes per hour (ACH) are measured under test conditions (around 20 times the rate from normal wind and stack pressures) for comparison purposes and are not representative of natural ventilation.

MODELLING OF HOUSES

Five of the HEEP houses have been modelled in the thermal design tool SUNREL (Deru et al 2002). The creation of a model enables temperature influences from occupants (e.g. increasing ventilation through opening windows or increasing internal gains) to be compared as well as physical influences (design and materials of house). Comparisons can also be made between the HEEP monitored and modelled temperatures.

A thermal simulation model can only be a representation of a house, the operating conditions and the external climate. Modelling was based on information from the HEEP database, including the house audit and occupant survey. Original house plans were not always available, and even if available the house may not be built to the exact specifications on the plan. The models were made as realistic as possible with scheduled opening and closing of windows, wind-driven natural ventilation and appropriate internal gains – although again assumptions had to be made.

The use of local meteorological data was found to be very important, as expected due to the high correlation between external temperatures and the indoor summer temperatures. Unfortunately HEEP could not monitor the external temperature (or other climate data such as wind speed, wind direction, humidity or solar radiation) on-site for all the houses.

Temperature outputs from the SUNREL models were compared to the monitored HEEP data. Living room temperatures were found to track well, but the model tends to have higher maximum temperatures during the day than found in the houses. Reasons for this difference are still being investigated, but are thought to relate to the models representation of the occupants use of windows.

A series of sensitivity studies were carried out on the models to explore the relative importance of different construction, design and occupant behaviours. These included: increasing overhangs; increasing infiltration; changing from single to double glazing; halving the size of the windows; doubling the size of the windows; three levels of insulation (none, Code, high); rotating the house to have a north facing living room (one model was already north); changing internal walls to exposed concrete; changing all floors to exposed concrete; increasing shading from neighbouring trees houses etc; and increasing ventilation.

The changes that made the most significant difference to increasing the living room summer peak temperatures were:

- doubling the size of the windows
- going from no insulation to Code levels of insulation (although going from Code to higher made little difference)
- orientating the living room towards north
- increasing internal gains.

The changes that made the most significant decrease in reducing the summer peaks were:

- increasing usable mass through either exposed mass walls or floor
- decreasing window size
- increasing ventilation.

Each of these would appear to have a basis in both physics and common sense: increasing window size increases solar gains; increasing thermal insulation increases heat retention; and increasing thermal mass increases temperature stability.

CONCLUSIONS

The external climate has been found to have the greatest effect on living room temperature, with newer houses warmer and more likely to overheat. No one design or construction feature could be identified as the cause of this increase, it appears to be rather a combination of new house features. Given the changes in design and construction over the years, it was not possible to check all possible reasons.

Modelling has suggested some of the design and construction features which can cause a house to overheat e.g. large amounts of glazing. Occupants were also found to be able to increase the temperature by increasing internal gains in the house, although the modelling has suggested it may be possible to reduce the effects of large amounts of glazing by other factors e.g. exposed mass. Newer houses also have a larger diurnal temperature range, possibly from having larger windows allowing more solar gains into the space during the day and more losses at night.

With climate as the strongest influence on living room temperature, expected changes due to climate change will mean that internal temperatures are likely to also increase.

Warmer living rooms combined with the increase in heat pump installations in New Zealand suggest that cooling in summer is likely to become more common. Heat pumps may solve the problem of the over-heating house, but require electricity when potentially a good design would have stopped the house from over-heating in the first place.

To have a comfortable house without active cooling, it is best to plan and design for one before building. It is much harder to 'fix' once the house is built. The analysis suggest that the key areas which need to subject to careful design are the glazing area, usable mass and the ability to control ventilation through opening windows.

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REFERENCES

BASSETT, M. (1992) House Airtightness Variation with Age. *10th International Passive and Low Energy Architecture (PLEA).* Auckland, New Zealand.

BUCKETT, N. R. (2007) National Impacts of the Widespread Adoption of Heat Pumps in New Zealand. *SR169.* Judgeford, BRANZ.

DERU, M., JUDKOFF, R. & TORCELLINI, P. (2002) *SUNREL - Technical Reference Manual,* Colorado, National Renewable Energy Laboratory (NREL).

DONN, M. & THOMAS, G. (2001) *Designing Comfortable Homes,* New Zealand, Wellington, Cement and Concrete Association of NZ and EECA.

FRENCH, L. J., CAMILLERI, M., ISAACS, N. P. & POLLARD, A. (2007) Temperatures and heating energy in New Zealand houses from a nationally representative study - HEEP. *Energy and Buildings,* 39**,** 770-738.

FRENCH, L. J., CAMILLERI, M. J., ISAACS, N. P. & POLLARD, A. R. (2006) Exploration of Summer Temperatures in New Zealand Houses and the Temperature Drivers. *The 2006 Windsor Conference for the Network for Comfort and Energy Use in Buildings - Getting them right.* UK.

ISAACS, N.P. (1993). *Thermal Efficiency in New Zealand Buildings: A Historical Overview*. Centre for the Building Performance Research, Victoria University of Wellington.

ISAACS N.P. (1999). 'Performance Based Building Energy Efficiency Code'. *Proc. Global Building Model in the Next Millennium Conference.* Melbourne 12-15 April 1999. (BRANZ Conference Paper 63: 108-118).

ISAACS, N. P., CAMILLERI, M. J., FRENCH, L. J., POLLARD, A. R., SAVILLE-SMITH, K., FRASER, R., ROSSOUW, P. & JOWETT, J. (2006) *Energy Use in New Zealand Households: Report on the Year 10 Analysis for the Household Energy End-use Project (HEEP)*.

JAQUES, R. (2000) Summertime Over-Heating in New Zealand House: Influences, Risks and Mitigation Strategies. *SR089.* Judgeford, BRANZ.
STANDARDS NEW ZEALAND (2003) NZS PAS 4244:2003-Insulation of Lightweight-Framed and Solid-Timber Houses. Standards New Zealand.
STANDARDS NEW ZEALAND (2004) NZS PAS 4218:2004:Energy efficiency - Small building envelope. Standards New Zealand.
STATISTICS NEW ZEALAND (2005) Profile of New Zealand. Statistics NZ.