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PRELIMINARY FINDINGS ON THE INTERNAL TEMPERATURES IN A SELECTION OF WANGANUI HOUSES

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Preliminary Findings on the Internal Temperatures in a Selection of Wanganui Houses

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1. Abstract

BRANZ has monitored the internal temperatures in a selection of houses in Wanganui since 1996. The measurements made in 1997, as part of a FRST funded project, recorded temperatures at fifteen minute intervals at up to ten points within each house. The measurements made in 1996 recorded temperatures at two or three points within each house.
These houses are a selection of the houses used for the Household Energy End-Use Project (HEEP) which provide a detailed socio-demographic survey providing information on the occupants and their behaviour as well as additional information on the household energy use at appliance level.
This paper provides some initial findings of the temperature monitoring conducted in these houses including an exploratory examination of the difference in temperatures within the house as well as the daily temperature profiles. A non-statistical comparison to the temperature levels found in the 1971 Temperature/Insulation Survey of New Zealand houses is included.

2. Introduction

It is important to understand the indoor climate maintained within residential buildings as it is a determining factor in the energy consumption of the building as well as the comfort and health of the occupants[1]. One of the important characteristics of indoor climate is the indoor air temperature. Very little is known about the indoor temperatures found in New Zealand houses. The last major study was undertaken by the New Zealand Department of Statistics[2] in 1971/72. Indoor temperature patterns are controlled by a series of factors. The most important factors are thermal performance of the building, the heating system, the climate and the occupants' behaviour. Thermal computer simulations show significant differences in indoor climate conditions between houses with different insulation levels and thermal mass.[3, 4]

Since early 1996 BRANZ has logged indoor temperature levels in 28 houses in Wanganui. In each of the houses the air temperature is recorded at up to ten locations. The time resolution of the logging is 15 minutes and each house is logged for approximately 5 months. This 5 month period covers generally half a winter and half of the summer period and the in-between transition season. This allows to treat the recorded data as being representative of a full year. A more detailed climate normalisation procedure is currently being developed.

The houses used for the temperature monitoring are houses that are used for the Household Energy End-Use Project[5]. There is a considerable amount of additional information collected about these houses. Energy usage is collected for a number of the appliances and electrical circuits used in the house. The house occupants undertake a general survey that also includes questions in regard to their behaviour that may reflect on energy usage and the indoor temperatures within the house. An energy audit of the house is also conducted.

3. Temperature profile shapes

Two fundamental issues concerning the measurement of indoor temperatures have to be resolved. The first is the definition of the "indoor temperature". There are three principal heat transfer mechanisms which lead to human thermal perception of warmth: convection, radiation and conduction. The equipment currently used for the temperature logging records a combined radiative and convective temperature. The loggers are positioned so they are not struck by any radiant light sources as this affects the temperatures the loggers report. The degree to which the recorded temperature is a measure of the temperature which would be perceived by the house occupants has yet to be determined. The second fundamental issue is the location of the temperature recording. The temperature in houses shows significant variations from zone to zone in the house and vertically through thermal stratification. The factors contributing to the stratification of temperatures within two houses are examined in Section 0.

The following graph (Figure 1) shows the temperature profile in one of the houses over a three day period. During the first two days no heating was applied. The three living room temperatures are closely linked. On the third day approximately 4kWh heating was applied. Two of the temperatures have increased by 5°C, whereas the other temperature has only increased by 2 °C. Thus characterising the response of a room when heating is applied is complicated by the different temperature levels within in the room.

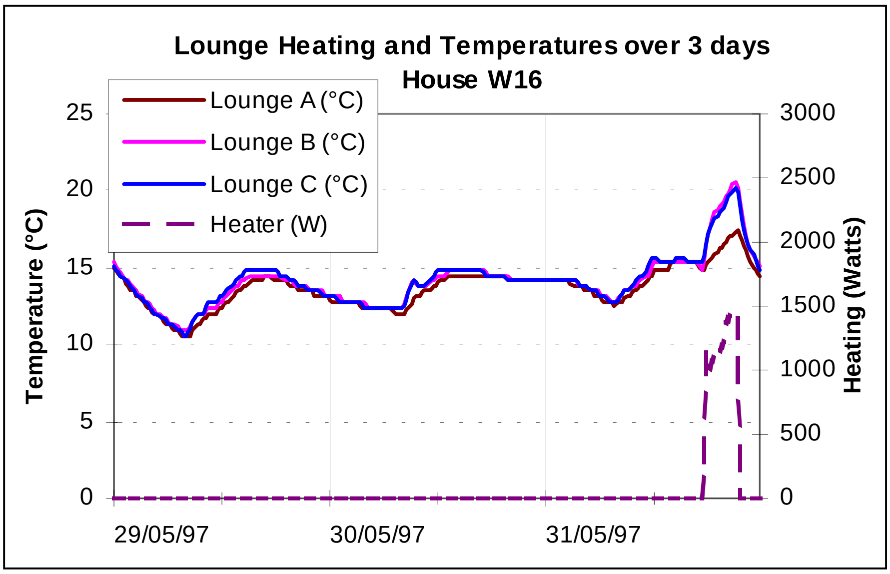


Figure 1 Three day temperature and heating profile for house 16.

4. Temperatures and the amount of heating

Figure 2 shows the change of the average daily temperature profiles during the seasons for house 10. Two main effects can be seen in the figure. Firstly the summer indoor temperatures are very consistent, however, the winter temperatures deviate from the summer temperature patterns with a much more shallow recovery in the indoor temperature from approximately 9:00 am onwards. It is believed that this is an effect of the reduced amount of solar radiation during the winter months. The other effect seen in Figure 2 is the deviation of the winter

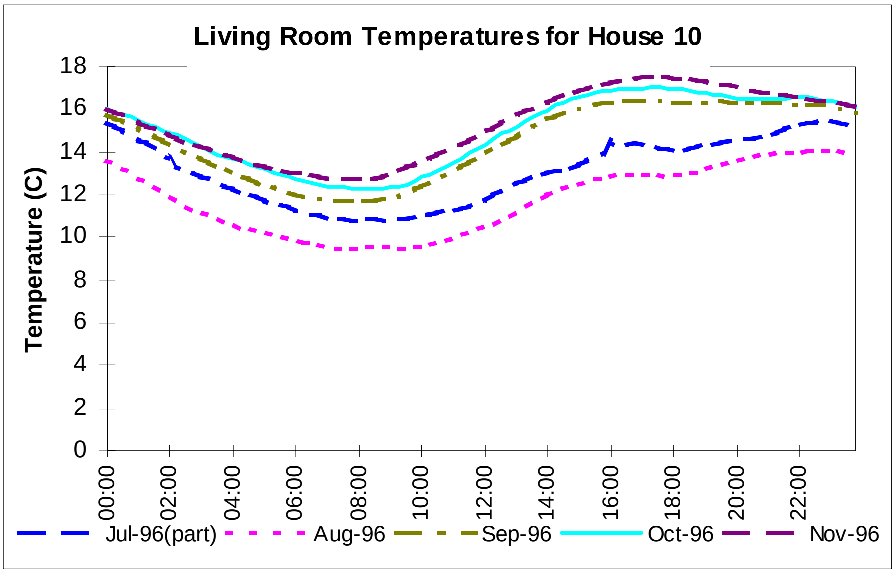


Figure 2 Average daily temperature profiles o f the living room for 5 months

profiles in the evening which is due to the application of heating. Figure 3 gives the profiles of the average daily heating for the same period. It can be seen from this graph that for July and August, the more heavily heated months, the heating is predominantly taking place from approximately 6:00 pm onwards which corresponds to the time when the deviation was seen in Figure 2. The effects of the “blip” in the heating for July around 4:00 pm can be seen as a resulting “blip” in the July temperature record.

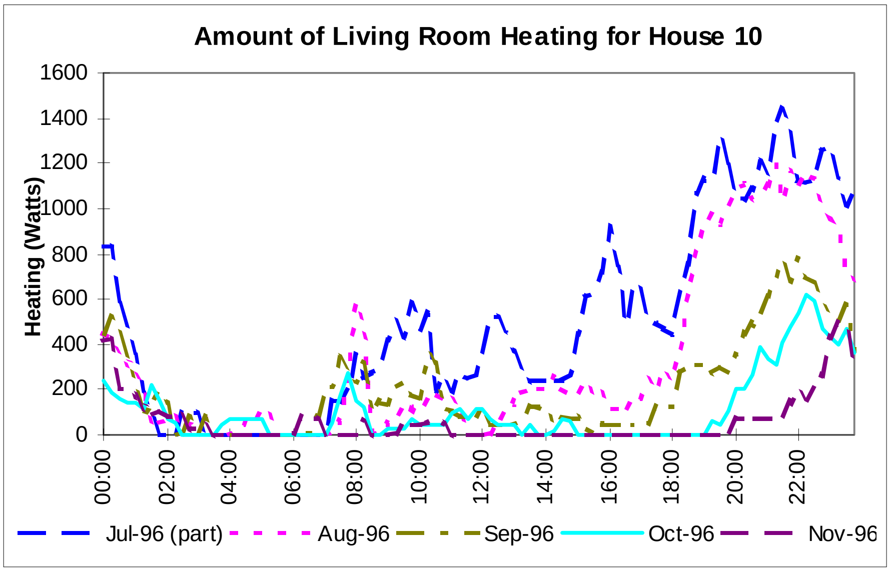


Figure 3 Average daily profiles of the living room heating for five months

When daily values for temperatures are considered, the response information in the temperature profile due to the applied heating is lost. As the heating is driven by the occupants, the process of summarising the profiles to daily averages is dependent on how much of the time the occupants are home and what conditions they demand when they are home. Comparison of the daily heating with the daily indoor temperature or the daily outdoor temperature for the measured houses shows no apparent linkages.

5. Temperature stratification within houses

The stratification of internal temperatures within houses, while readily apparent, can be difficult to quantify due to the large number of causes whose impact can not be reliably measured. Some of the conditions that give rise to internal temperature gradients can be easily controlled while others are difficult to control. They include such conditions as climate, building performance and behaviour of the occupants. The following case study is a comparison of two houses where the temperature stratification in each of the two houses is quite different. Figure 4 gives the temperature stratification within house 16 where the temperatures vary quite considerably depending on the location of the sampling point within the house. Figure 5 shows a contrasting situation where the temperature stratification for house 17 is hard to detect. The houses are within 500m of one another. The external temperature measured at both locations is very similar. Both houses are three bedroom houses and are of similar size. House 16 is an older house and was constructed about 40 years ago while house 17 was is a newer house constructed about 10 years ago. The designs of the two buildings also differ appreciably; house 16 has separate kitchen, dining and living rooms whereas house 17 has open plan living areas with no restrictions between the kitchen, dining and living rooms. The internal load in house 17 with its six occupants is also much higher than that for house 16 with its two occupants. Since most of the energy used in household appliances is ultimately converted into heat and released into the environment, the energy used by appliances gives a good indication of the “free” internal gains within each house.

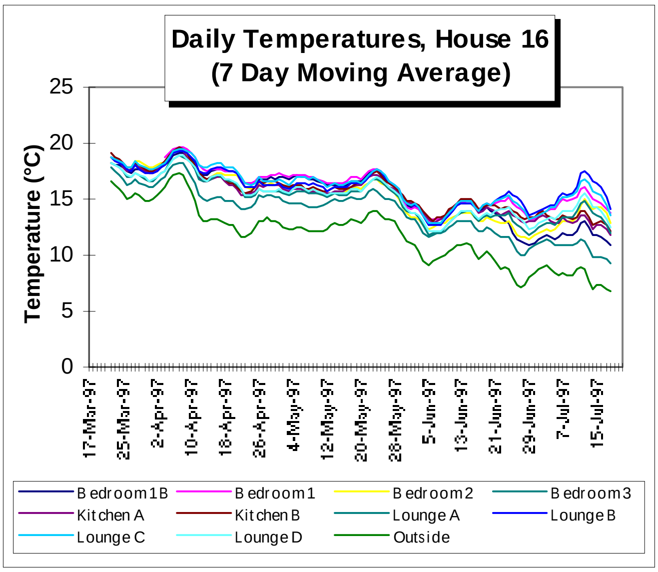


Figure 4: Daily temperature profiles in House 16

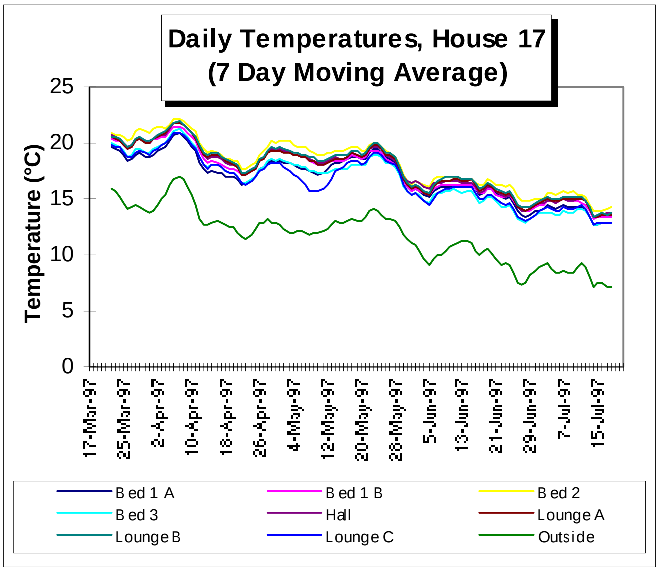


Figure 5: Daily temperature profiles in house 17

These internal gains can provide significant amounts of heat to a house. The use of appliances differs appreciably between the houses. Figure 6 and Figure 7 show the mean power demand in houses 16 and 17. In order to increase the number of logged appliances some of the appliances were logged only for part of the 5 month period†. The positions of the appliances within the house may also be important. For house 17 the 500 litre chest freezer is in the living space and the clothes drier (which is used heavily, using over 40 kWh of electrical energy per week) is in an adjoining room. Both of these appliances add significant contributions to the heating. The total load in house 16 shows a comparatively steep rise between the summer and the winter season. Some of this increase can be explained through the increase in heating energy consumption. As the preceding discussion shows there can be many causes of temperature stratification and not just the level of applied heating.

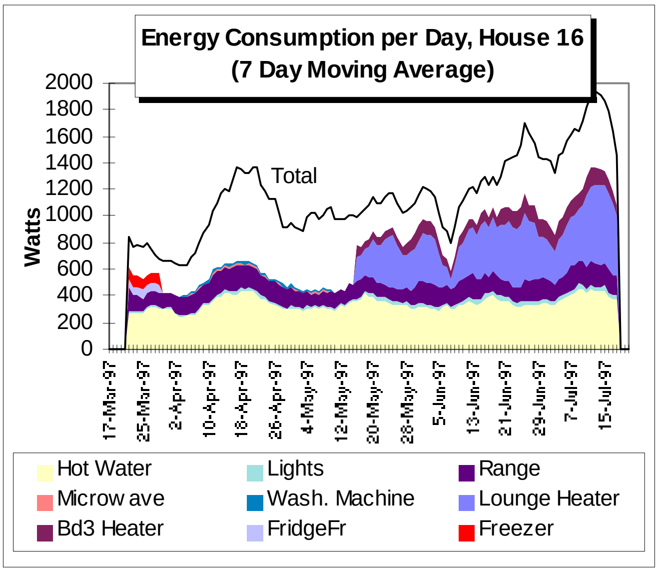


Figure 6 Energy consumption in house 16.

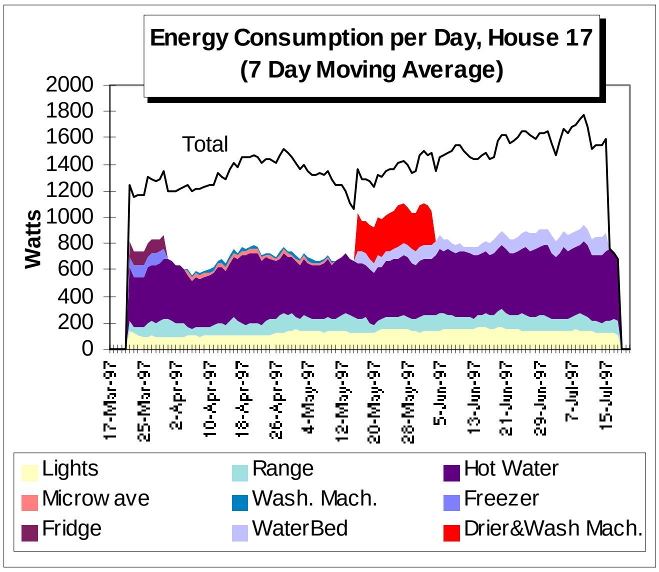


Figure 7 Energy consumption in house 17.

† Where an appliance has only been logged for a part of the logging period it can be possible to extend the usage for that appliance if the usage of the appliance does not vary considerably. For example, appliances like refrigerators and freezers which were only logged for a short time did not require further logging as the day to day difference in energy is small.

6. Comparison of temperatures with 1971

As part of the 1971-72 Survey of Household Electricity Consumption[6] a subset of houses were chosen to examine the temperatures and insulation levels that the households were maintained at. The results of this Temperature/Insulation study have been reported by the Department of Statistics[2]. These results are shown for August and September of 1971 in Table 1.

Region	Kitchen	Lounge	Main Bedroom
Northern North Island	17.8 °C	17.7 °C	16.1 °C
Southern North Island	16.4 °C	16.6 °C	15.1 °C
Christchurch	15.3 °C	15.2 °C	13.8 °C
Southern South Island	15.0 °C	13.6 °C	12.6 °C

Table 1 Indoor temperature levels found in August and September 1971 from the 1971-72 Temperature/Insulation survey.

The Northern North Island region includes houses in Auckland and Hamilton. The Southern North Island includes houses in Wellington, Paraparaumu, Horowhenua and New Plymouth. The Southern South Island includes houses in Dunedin and Southland.

The indoor temperatures reported in the 1971 survey comes from a device known as a temperature integrator and the value given is the average temperature for the duration the temperature integrator was recording. The equipment deployed since 1996 to measure temperature in Wanganui are Tinytag temperature dataloggers. These dataloggers have been configured to record the average temperature over fifteen minutes at every quarter hour of the day. The average of the readings of the Tinytag dataloggers over the course of two months would be equal to the reading from one of the temperature integrators over the same period. Temperatures were recorded at a number of points within each house as well as one point outside near the house.

The 1971/72 Temperature/Insulation survey also reports an average of the outside temperatures, weighted by the number of houses at each location, as reported by the weather station nearest the house[7]. These temperatures for the four regions are given in Table 2.

Region	Reported Outside Temperatures.
Northern North Island	12.0 °C
Southern North Island	11.0 °C
Christchurch	9.3 °C
Southern South Island	8.6 °C

Table 2 Outside temperature levels for the four regions for August and September 1971. The temperature for the region is a weighted average of the nearest weather station to each house chosen to represent the region.

The New Zealand Meteorological Service data[7] for August and September 1971 gives a mean outside temperature for Wanganui of 11.2°C hence Wanganui is most closely represented by the Southern North Island region. The mean temperature predominantly used by weather stations is an average of the minimum temperature and the maximum temperature over the same day. This procedure produces numbers that are similar to the true average temperature at that location, however as the mean temperature only depends on the extremes of the day it is a biased estimator of the average temperature. The difference between the mean temperature and the true average temperature at each location will vary. The temperature information collected from Wanganui can be used to construct both a true average temperature or a mean temperature (average of the maximum and minimum temperatures over a day) from each of the temperature dataloggers. As the true average temperature is more representative of the actual conditions it was decided to take this average as the measure of the indoor climate which is consistent with the method used in 1971.

It is also possible to obtain a daily measure of the mean outside temperature recorded for Wanganui from the NIWA climate database[8]. In 1996 NIWA recorded a mean outside temperature for August and September of 11.4°C and for 1997 the equivalent period had a mean outside temperature of 10.5°C. It was also found that the indoor temperatures (true daily averages) measured in Wanganui are correspondingly higher in 1996 than in 1997 as shown in Table 3.

	1996		1997	
	Temperature	No. houses	Temperature	No. houses
Kitchen	16.2 °C	1	14.8 °C	9
Lounge	16.1 °C	5	14.8 °C	10
Main Bedroom	17.0 °C	3	13.2 °C	10
Outside	11.4 °C	—	10.5 °C	—

Table 3 Comparison of the indoor temperatures between houses for August and September 1996 / 1997.

As the number of houses sampled is small, no conclusive test of the significance of the difference between the two years can be undertaken, however the pattern suggests that further investigation of the dependence of the indoor temperatures on the outdoor temperatures is required.

Figure 8 provides a comparison of the daily lounge temperatures in house 19 and the daily mean outside temperature recorded for Wanganui. The equation given, y = 0.46x + 9.8, is the equation of the fitted straight line. This means that a 1 °C difference in the outside temperature leads to a temperature difference inside of approximately 0.5 °C. One limitation of this method is how much heating is taking place within the house. When no heating is used within the house, the fit of the straight line to the data would be very good, however when heating is applied it is suspected that the heating would be more frequently and more heavily applied when conditions outside are cold so the effect of heating is to usually shift data points for low outdoor temperatures (ie the left hand side of Figure 8) upwards. The effect of heating is then to reduce the slope of the fitted line and to reduce the quality of the fit.

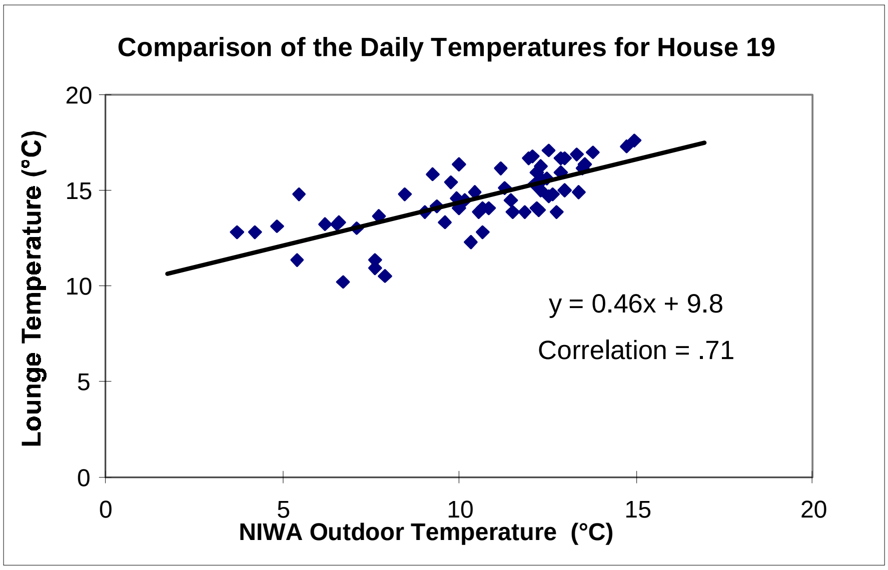


Figure 8 Plot of the daily lounge temperature for House 19 and the daily temperature recorded by NIWA for Wanganui over August and September 1997.

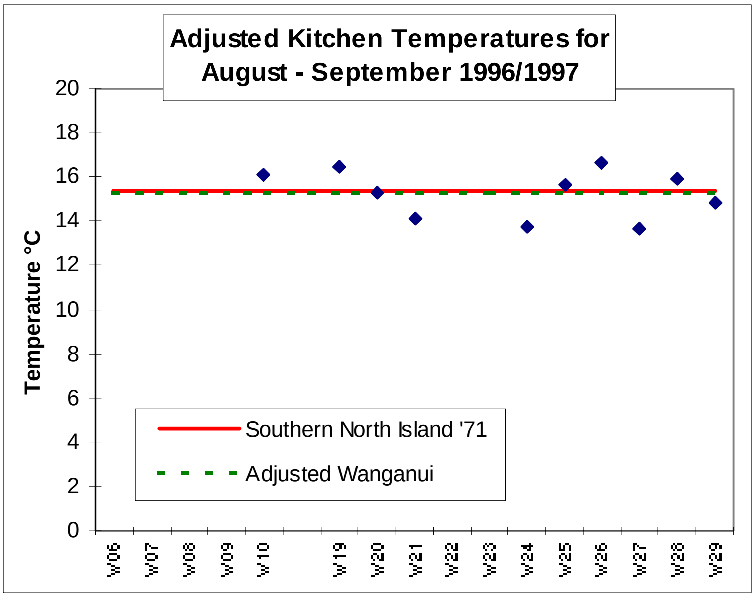
A further complication is how localised the conditions are that effect the house and whether the weather station is close enough to measure the temperature that influences the house. When the weather station temperature is replaced with a measure of the outside temperature at the site, using a Tinytag temperature logger, the quality of the fit is improved. Additional analysis is required to establish the size of the improvement and to determine what variation there is with it.

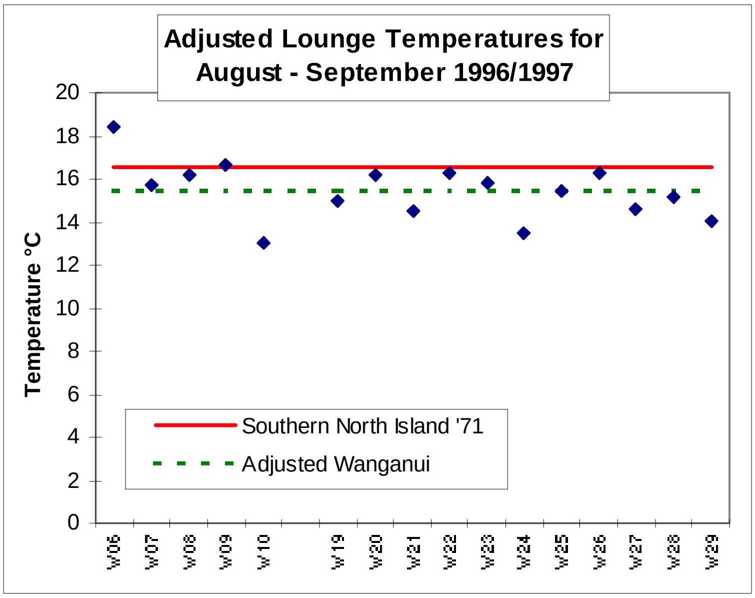
Comparisons, like that shown in Figure 8, were made for both 1996 and 1997 and for each of the lounge, kitchen and bedroom temperatures. The comparisons showed consistent correlations with all except one (the kitchen temperature for house 19) having correlations above 0.7. The outside temperature can then be seen to be an important factor in the indoor temperatures found in houses. While there is some variation in the slope of the regression lines, the average of each year for each location is approximately the same (0.5). To make comparisons between the years the difference in outside temperature between the years will be used to adjust the measured indoor temperatures. The base year will be taken as 1971 year so the correction for the 1996 temperatures will be to subtract 0.1 °C from the 1996 values whereas the correction for the 1997 temperatures will be to add 0.35 °C.

Figure 9 provides plots of the adjusted internal temperatures found in 1996 and 1997 for the houses in Wanganui. Houses w06 to w10 were measured in 1996 and are shown on the left of each of the graphs. House w19 to w29 were measured in 1997 and are shown on the right hand side of the graphs. The solid line covering both years is the corresponding temperature from the 1971 survey for the Southern North Island region and the dashed line covering both years is the average of both the 1996 and 1997 temperatures adjusted for the external temperatures as described in the previous paragraph.

From the graphs it can be seen that the 1971 and 1997 kitchen temperatures seem comparable while the temperatures in lounge and bedroom are colder for 1996/1997 than the temperatures found in 1971. However two limitations must be mentioned. First is the small sample size, especially for 1996. The second limitation is the accuracy of the correction for the severity of each winter as described above.

An understanding of the yearly variations in indoor temperature and how they are related to other parameters like the weather station temperatures is required to make better use of existing information such as the 1971 Temperature/Insulation survey which has provided a reference level.





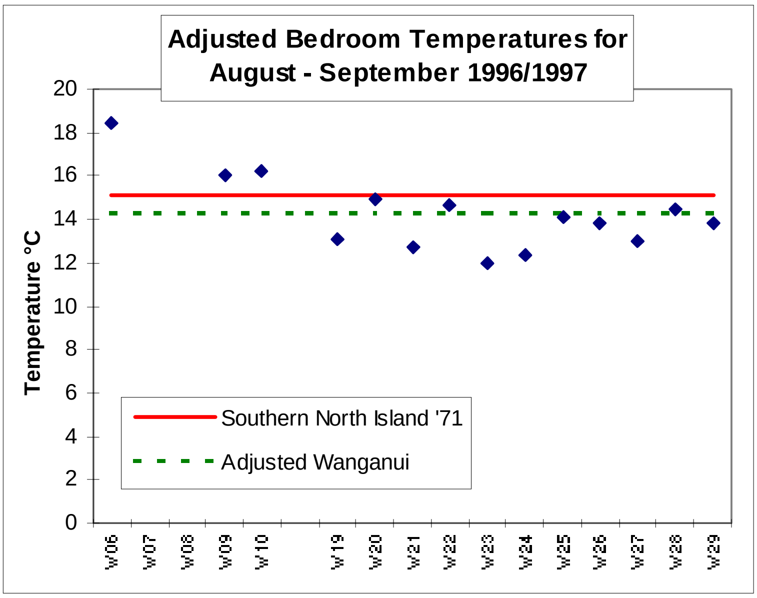


Figure 9 Plots of the 1996 and 1997 adjusted Wanganui indoor temperatures as compared against the level from the 1971 survey

7. Conclusions

The temperature profiles from a house provide a considerable amount of information about the heating that occurs within the house and the comfort expectations of the occupants. Using temperature dataloggers the dynamic response of the house to various modes of heating (occupant driven heating, solar heat gains, etc.) can be seen when it occurs. With a number of drivers responsible for changes in the temperature a method is required to summarise the impact of each of these responses seen in the indoor temperatures. The use of the daily mean value for the indoor temperature loses information about the variation that occurs within that day. The daily temperatures do however provide good comparison for the indoor temperatures against the outdoor temperatures as for the majority of the time no heating is applied in most houses and so the average approaches the free-running condition for the house. Comparison of similar temperature measurements over different years (such as the indoor temperatures used in the 1971 Temperature/Insulation study) or at different times of the year introduces difficulties in that they can not be compared without making an adjustment in the temperatures due to the variation in outside temperatures between the seasons. As a result an understanding of the dependence of the indoor temperature measurement on the outdoor temperature is required.

8. Acknowledgements

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