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The Impact of Solar Radiation on the Air Temperature within a Residential Building

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Abstract

This paper reports on the field measurements of the indoor temperature in a typical New Zealand house. The indoor temperatures were measured at four distinct heights for two periods of 25 days; one during June 1999 when a radiant gas heater was used and the other during September 2000 after the heater was replaced with a gas convective heater. Measurements of outside temperature and horizontal global solar radiation were also collected from a nearby meteorological station. The influence of the solar radiation on the vertical temperature distribution was examined and compared with the two different types of heating used.

1. INTRODUCTION

Winter space heating is a large component of the energy used in New Zealand houses (Stoecklein *et al*., 1997). The amount of energy required is determined by the climate, the physical properties of the building and the comfort expectations of the occupants. Purchased heat requirements for a building can be minimised with appropriate design that generally looks to make effective use of the available solar radiation. This paper investigates a typical New Zealand house to see what impact solar radiation has on the indoor temperatures within that house.

2. EXPERIMENTAL SETUP

The house for examination was in Palmerston North in the lower half of the North Island. The house was built in the early 1970's to a design that was frequently replicated in the area at that time. The exterior of the house is shown in Figure 1. The construction of the house consists of timber framing and includes a suspended timber floor, timber framed glazing and a pitched timber roof clad with corrugated galvanised steel. The house has flat ceilings at a height of 2.4 metres above the floor. The northern and eastern walls have a brick veneer cladding on the exterior walls. The living room is located centrally within the house with large windows in the northern wall and is seen to the left in Figure 1.

Measurements of the indoor temperature within the living room were made for two periods of twenty-five days; one starting from the 20th May 1999 while the other started from the 1st September 2000. For the 1999 case, an extensive investigation of the living room temperatures was made (Pollard, 2001). Eighteen temperature loggers were placed around the living room. These included two temperature loggers placed in the centre of the room (at

Figure 1 Exterior of the Palmerston North house

a height of 1.9m), three and four temperature loggers placed at differing heights in the southwest and northwest corner of the room to provide information on the vertical temperature patterns within the room and three temperature loggers along each of the southern wall and eastern walls. The eastern wall had a flued, radiant, natural gas heater. A temperature logger placed on the top of the gas heater to provide an indication when the heater was being used.

In the 2000 study, because interest was limited to examining the vertical temperature patterns, only the vertical temperature array in the southwest corner was used. This array had temperature loggers placed at heights of 0.4 m, 0.9 m, 1.4 m and 1.9 m. However, due to configuration problems no data was available from the temperature logger placed at 0.4 m. The space heating used within the living room changed between the two periods monitored. The flued, radiant, natural gas heater used in 1999 was replaced in 2000 with a flued, flame-effect, convective, natural gas heater.

The temperature loggers were set with a five-minute interval between readings. Additional hourly measurements, covering the same time periods of the external air temperature and global horizontal solar radiation were extracted from the NIWA climate database (Penney 1997) taken from Palmerston North Airport, about 4 km to the northeast of the house. The global horizontal solar radiation reported in the NIWA database is the solar radiation received (in MJm^{-2}) for the previous hour.

3. RESULTS

The hourly measurements for the first nine days of the data collected for 1999 are shown in Figure 2. ***Tin*** is the temperature reported by the centre of room temperature logger, ***Text*** is the temperature recorded at the Airport, ***Rext*** is the global horizontal solar radiation also recorded at the Airport and ***Heat*** is an indicator variable as to whether the heater was on or off. It can be seen that the occupants of the house use the radiant gas heater in the evenings and there is little overlap between the times of the solar radiation and heater operation.

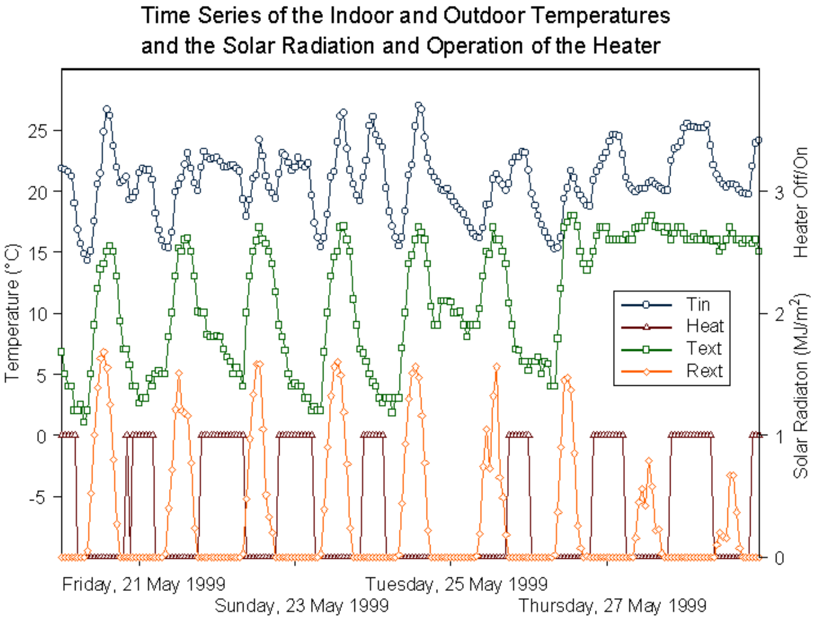

Figure 2 The measured parameters over a number of days in 1999

In order to examine the average effect of the solar radiation, the gas heater use and the external temperature on the indoor temperature achieved within the house an average for each of these variables was calculated for each hour of the day over the twenty-five day period. These average daily profiles are shown in Figure 3. It can be seen from Figure 3 that the occupants of the house frequently operate the gas heater between midnight and 6am. It should be noted that the occupants were in full time employment and were away from the house during most of the day. It can also be seen in Figure 3 than the peak of the solar radiation occurs before the peak of the indoor temperature, suggesting that the solar radiation has a delayed effect on the indoor temperature. From a cross-correlation between the indoor temperature and the solar radiation, it was seen that the maximum correlation occurs between the variables when a lag of two hours was applied to the solar radiation.

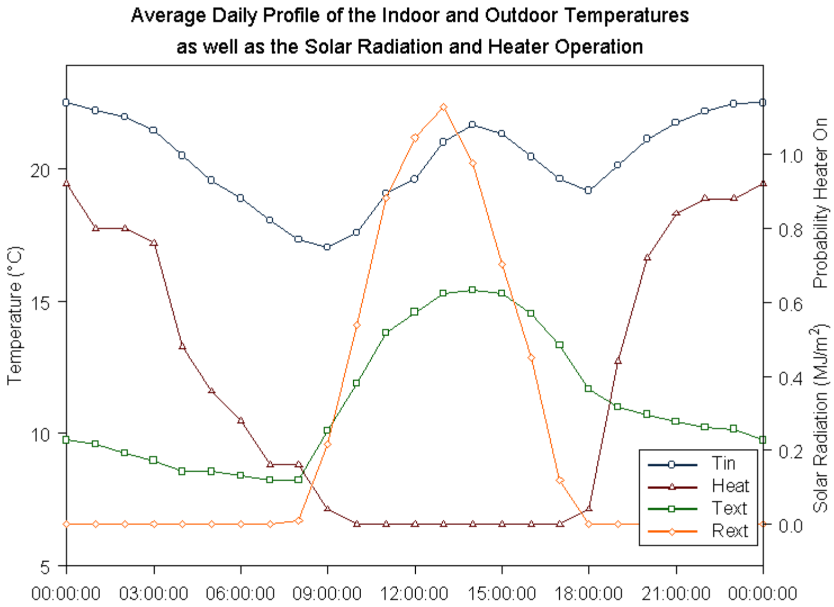

Figure 3 Average daily profile of the measurements shown in Figure 2

A multiple regression of the hourly indoor temperature was tested against the operation of the heater, the external temperature and the solar radiation lagged by none, one, two or three hours. A lag of two hours provided the best fit with a multiple r^2 value of 0.68. The fitted function was

$$\boldsymbol{Tin} = 15.03 + 5.02\times\boldsymbol{Heat} + 0.25\times\boldsymbol{Text} + 2.40\times\boldsymbol{Rext} \quad (1)$$

The peak of the average solar radiation occurs at 13:00 and has a value of 1.13 $MJ\,m^{-2}$. The solar radiation will then have an average effect of about 2.7 °C on the indoor temperatures recorded at 15:00. The measured solar radiation at 13:00 varied from a value of 0.16 $MJ\,m^{-2}$ to 1.68 $MJ\,m^{-2}$ corresponding to an average solar contribution to the 15:00 indoor temperature of between 0.4 °C and 4.0 °C.
Improvements to the accuracy of Equation 1 could be made by better accounting for the deviation between the measured values of the external temperature and solar radiation and the conditions influencing the temperature within the living room. For example restriction of the solar radiation in the afternoon due to shading from the northeastern bedroom walls has not been considered.

4. VERTICAL TEMPERATURE DISTRIBUTION

From the measurements in 1999 it was seen that there was a systematic variation in temperature within the living room that could be related to the height of the temperature measurement (Pollard 2001). From the literature, it has also been found that the type of heating employed within the room impacts on the temperature distribution (Inard *et al*. 1996, Howarth 1985). That work however was conducted in laboratories and considered static situations when a particular heater was operating. Heating due to solar radiation is time dependent and field measurements are required to account for such factors as external shading, furnishings, and occupant interactions such as closing curtains or shutters.

A large amount of data has been collected from the vertical temperature observations in the Palmerston North house. From the 25 days of measurements in 1999, about 28800 measurements were collected on the indoor temperature at four heights in the southwest corner of the living room. With three variables of interest (temperature, height and time) plotting the data requires some care.

Four days of measurements from 1999 are shown in Figure 4 and six days of measurements from 2000, shown in Figure 5. In the graphs, time is shown on the x-axis (midday is indicated by the vertical lines through the date labels) and height on the y-axis. The shading, to the scale on the right, indicates the temperature in 1°C increments. There is a horizontal line in Figure 4 and Figure 5 indicating a height of 1.1 m. It should be remembered that the data for 2000 covers a smaller range of vertical displacement of 1.0 m (due to the missing

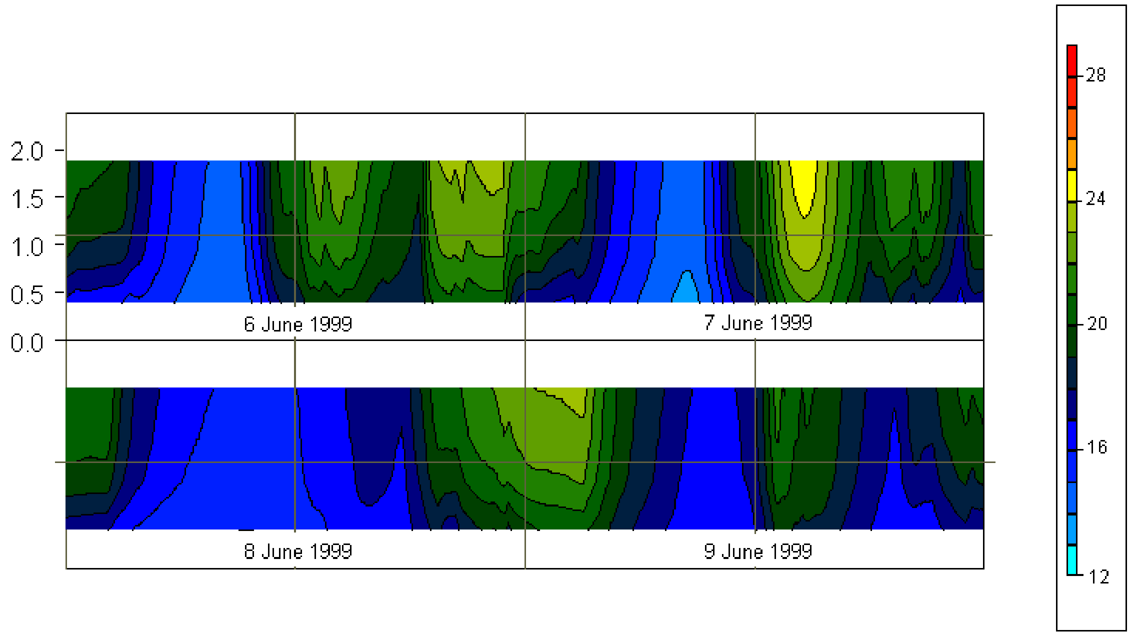

Figure 4: Vertical temperature profile, living room southeast corner, 1999

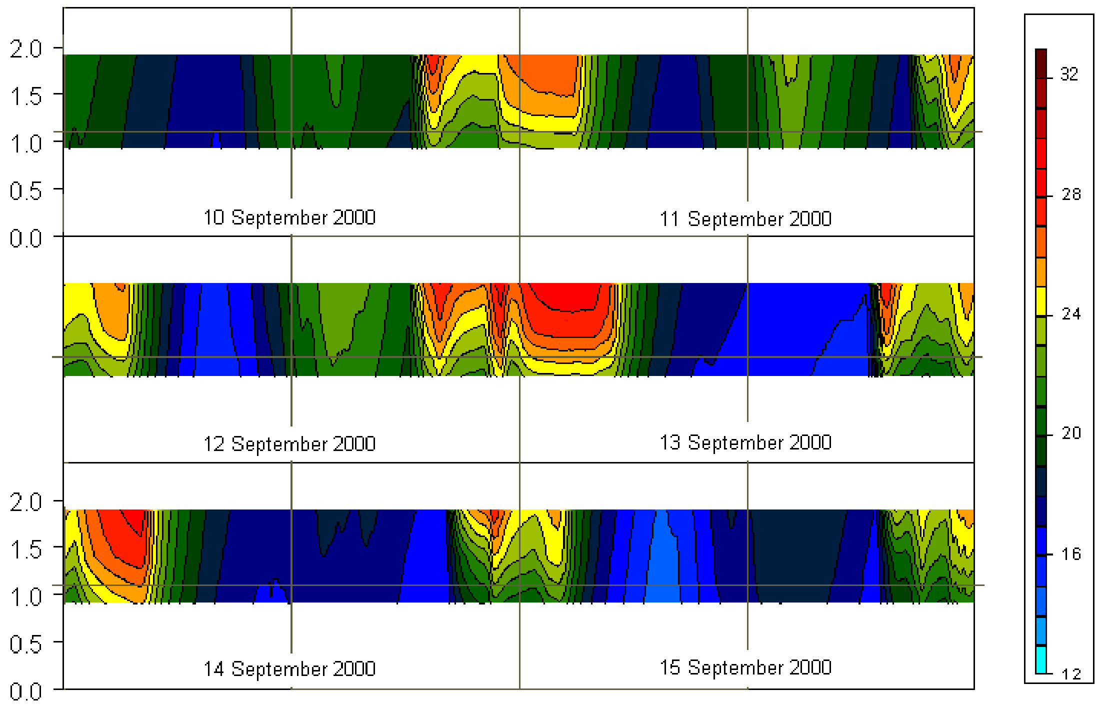

Figure 5: Vertical temperature profile, living room southeast corner, 2000

measurements from 0.4 m) as opposed to the 1.5 m vertical displacement in 1999. It should also be noted that the time of year for each measurement period is different with June closer to mid winter than September.

Figure 4 and Figure 5 shows that as the living room is being heated (due to the either the heater operation at night or solar radiation during the day) there is an increase in the vertical temperature difference (indicated by more temperature layers) between the high sensors and the low sensors. When the living room cools (due to heat conduction through the walls and infiltration heat losses) the vertical temperature difference is reduced. The most striking contrast between the temperature measurements for 1999 and 2000 is the change in the vertical temperature differences during heating. The convective heater, in use in 2000, produces greater vertical temperature differences than radiant heater in use in 1999.

Examining the twenty-five day periods hour by hour, gives the interval between 9pm and 1am as the time when the range of the vertical temperature differences is the smallest. This is the time when heating is most consistently applied. For 1999 (radiant heating) the temperature difference during this time between the temperature logger at 1.9 m and the temperature logger at 0.9 m was typically between 1.0 °C and 2.0 °C with an average of 1.3 °C. During 2000 (convective heating) the vertical temperature difference was typically between 3.0 °C and 7.0 °C with an average of 3.6 °C. When the building cools, the vertical temperature difference drops to below 0.6 °C and is more sensitive to individual heating events. In the afternoon the temperature difference due to solar radiation, between 1pm and 3pm, ranges between 0.2 °C and 1.5 °C and has a consistent average of approximately 0.7 °C for both 1999 and 2000. The layering of the afternoon temperatures is similar to that of the radiant heater.

The approximate head height of a seated individual (1.1 m) is taken as a reference height. Table 1 gives the average estimated temperatures (as well as their standard deviations) at this height for the period of solar gains and the period of evening heating for 1999 and 2000. The afternoon solar gains produce similar temperatures between the two years, which are only slightly lower than the temperature measured during the evening heating for 1999 (radiant heating). Therefore the level of temperature the solar radiation provides appears to be within the preference temperature range of the occupants.

Table 1 Temperatures during afternoon solar gains and evening heating

Year	Between 13:00 and 15:00	Between 21:00 and 01:00
1999 (radiant)	20.6 ± 2.2 °C	20.8 ± 1.4 °C
2000 (convective)	20.3 ± 2.4 °C	22.3 ± 1.7 °C

The temperatures measured during the evening heating for 2000 (convective heating) are, on average, about 1.5 °C warmer than the evening heating for 1999 (radiant heating). This difference in temperature may be due to differences in comfort between radiant heating and convective heating or may be due to the incorrect assumption that the height influencing comfort is head height (1.1 m) – a lower height, closer to the centre of the body, may be a better reference height.

The occupant's commentary on the change of heating is that the new flame effect convective heater is less noticeable while in operation in the room. They report that the difference in temperature between the living room and other rooms of the house are apparent when they move between rooms.

It is interesting to note that an energy conservation programme in Ireland (Fuller and Minogue, 1981) needed to make corrections to the temperatures recorded at high locations, 0.1 m from the ceiling, depending on the nature of the heating system.

5. CONCLUSIONS

Indoor temperatures within buildings are dynamic. The vertical temperature distribution within the living room of the house under investigation was seen to depend on the nature of the heating system employed. Convective heating produced a greater vertical temperature difference (3.6 °C) than radiant heating (1.3 °C). The solar gains were seen to produce a radiant effect on the afternoon temperatures within the living room, producing a vertical temperature difference approximately between 0.2 °C and 1.5 °C, with an average value of 0.7 °C. The afternoon temperatures were comparable to the evening temperatures when the radiant heater was used (1999).

6. REFERENCES

Fuller, T. and Minogue, P. (1981), *Efficiency and Energy Conservation Potential of Domestic Heating Systems*, An Foras Forbartha, The National Institute for Physical Planning and Construction Research, Dublin, Ireland.

Howarth, A. T. (1985), *Predictions of Temperature Distributions Within Spaces with Convective Heat Sources*, Proceedings of the CLIMA2000 World Congress on Heating, Ventilating and Air-Conditioning, 25-30 August, Copenhagen, Denmark.

Inard, C., Bouia, H. and Dalicieux, P. (1996), *Prediction of Air Temperature Distribution in Buildings with a Zonal Model*, Energy and Buildings 24 (1) 125-132.

Penney, A. C. (1997), *Climate Database (CLIDB) User's Manual*, NIWA Technical Report 4, National Institute of Water and Atmospheric Research, Wellington, New Zealand. (see also http://katipo.niwa.cri.nz/www_cli.htm)

Pollard, A. (2001), *Investigating the Characterisation of Temperatures Within New Zealand Buildings*, M.Sc. Thesis (in-preparation), Massey University, Palmerston North, New Zealand.

Stoecklein, A., Pollard, A., Isaacs, N. (ed.), Ryan, G., Fitzgerald, G., James, B., and Pool, F. (1997), *Energy Use in New Zealand Households - Report on the Household Energy End-use Project (HEEP) - Year 1* The Energy Efficiency and Conservation Authority, Wellington, New Zealand.