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A FIELD STUDY OF HEAT LOSS OF A SLAB FLOOR AND CONSERVATORY

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A Field Study of Heat Loss of a Slab Floor and Conservatory

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Abstract

This describes a five-year field study project being undertaken by the Building Research Association of New Zealand, on the thermal performance of slab-on-ground floors. One aim is to include the influence of wet soils. This first of two houses has now been monitored for 1 1/2 years. Patterns are emerging on the effect of seasonal and daily heat flow variations, sensitivity to heat storage, and sunshine. The paper is an interim report on the progress found to date in this work. This project is supported by funding from FRST.

1. INTRODUCTION

This paper describes the methods and preliminary results of a field study on one of two New Zealand houses with slab-on-ground floors, to investigate the floor heat losses of real buildings, including the effects of wet soil.

It had been generally accepted up till a few years ago that this component of space heating load on houses was well known. Then, work in the UK by Spooner (1982), (Concrete Research Association) suggested that these losses were perhaps half the then-current estimates. This report was quickly accepted by concrete interests, although there was no satisfactory explanation for this result; the soil properties in particular were not recorded.

Later work by the UK Open University (Everett 1985) reported the reverse result to that which Spooner observed, and accounted for both results by comparing the soil properties.

To give a clearer basis for building control decisions in NZ, there was deemed to be a need to demonstrate whether similar conclusions apply in the climate and soil types found here.

Finally, it is important to note that the whole subject of heat flow in the ground has been developed with only very limited observational data, and much of this has been over a rather short period. Heat flows in the ground are predicted to take many years to stabilise, and observations must be made over a period longer than the stabilisation time if they are to be reliable.

2. PROJECT DESIGN

The project involved the continual automatic recording of all temperatures and heat flows pertaining to the floor, and daily measurement of the soil thermal properties. Later computer processing would refine the results into useable heat loss coefficients.

A plan of this house is shown in Figure 1: it has a floor area of approximately 140 m², a small upper floor space not part of this study, masonry veneer external walls, and is built on peat soil using long steel-rail piles. Floors were covered with slate in the conservatory, and carpeted elsewhere except for toilet and bathroom. The occupants were required to maintain steady and even winter heating to 20°C or a little over. This was done under the control of normal room thermostats, using principally direct flued gas heating. The general configuration of instrumentation is illustrated in Figure 2. Although two houses have been instrumented, data collection had been possible in only one by early 1992.

2.1 Instrumentation

The instrumentation used on this project comprised four major parts:-

(a) Temperatures. Most of the ~150 temperature sensors on the concrete surface of the floor, plus miscellaneous points, were ordinary Cu/Con thermocouples. They were connected as difference thermocouples to indicate temperature relative to one of two reference blocks, whose absolute temperature was indicated by two semiconductor transducers with 0.1°C resolution. The reference blocks were externally insulated solid aluminium blocks about 50 mm total thickness. The temperature at each thermocouple was found by adding the reference block temperature to the difference between it and the thermocouple.

(b) Floor Heat Flux: Heat fluxes over substantially the entire floor area were recorded using 1.2 x 1.2 m or 0.6 x 1.2 m purpose built HFT's. These were made from 4.5 mm hardboard backed with 8 mm expanded polystyrene, and fitted with 16 (or 8) pairs of thermopiles. Each of some 150 HFTs for the house was calibrated, in sets of three, against one which was itself calibrated several times against a guarded hot box operated to ASTM

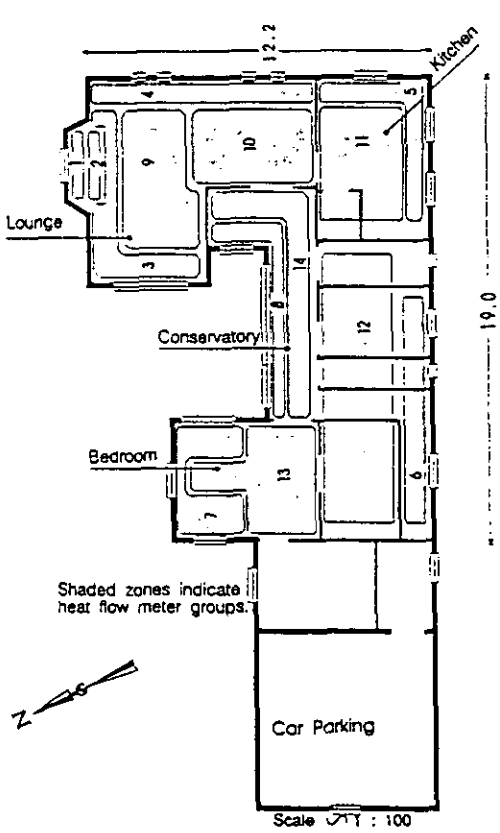

Figure 1 Floor Plan and Heat Metering Zones

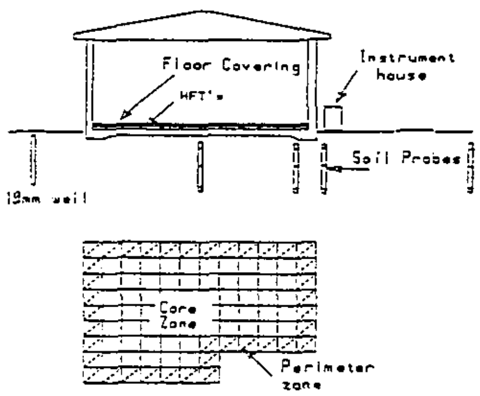

Figure 2 General Instrumentation Plan

C236. The calibration coefficient of these HFTs was around 6 ± 1 W/m^2.mV, and they had a thermal resistance of about 0.25 m^2°C/W.

A particular feature was incorporated in these HFTs to improve long term reliability. With such purpose-made devices there is a risk of thermocouple joint failure, so a "jointless" thermopile was used. In this construction the basic thermopile element was a single length of constantan wire, and each thermopile junction was formed by attaching two copper wire jumpers in parallel with the constantan. These function in a similar manner to plated thermopiles, with the final effect that failure during the 5-year project of any one joint would produce no change in HFT calibration. Failure of a second joint has 97% probability of also producing no change and a worst case outcome of changing calibration by 8%, without risk of losing continuity. Change of calibration would be indicated by a change of electrical resistance of similar proportion, and should be detected in routine testing.

(c) Soil Thermal Conductivity: The thermal conductivity of the soil at various positions was measured using a "needle probe", about 7 mm dia x 100 mm active heater length. These were built on 5 mm rigid glass fibre rods of 0.6 to 3.0 m length. The needle probes contained a single thermocouple immediately under a coiled nichrome tape heater.

The operating principle is to allow the probe to come to thermal equilibrium with the soil, and then suddenly apply a fixed heating power to the heater for some minutes whilst monitoring the temperature rise. The temperature rise is typically 2-5°C. The soil conductivity is then established from the temperature rise as described in Mulligan et al (1985) or Carslaw and Jaeger (1959). A review of the reliability of this procedure is given by Farouki (1986).

In this project the aim was to measure the soil conductivity once per day. In fact soil conductivity was measured using a manual version of the above procedure on several occasions prior to instrumentation, then measured daily for about a year until progressive continuity failure of probe heaters forced reversion to occasional manual measurement.

(d) Data Logging: Measurements from the above set of transducers was recorded on a BRANZ-built 54 channel microprocessor controlled datalogger with 12 bit ADC and precision preamplifier. The reading rates were quite slow - typically about 6 second intervals on low level signals from thermocouple and thermopile sensors. Eight complete scans of all channels were conducted each hour, and a 1-hour average calculated within the data logger from these eight readings, and finally written to magnetic cassette tape at 2400 baud in 4 digit NRZ ASCII coding. Soil temperatures are however all recorded individually with no averaging.

The 250-odd pairs each of floor temperature and floor heat flux sensors were wired individually back to terminals at the data loggers, where they were grouped into 14 data logger channels. This made it possible to detect and if necessary rewire to avoid any defects in individual sensors. The other 26 channels were used for single sensors on indoor and outdoor temperatures (5), floor edge temperatures (5), soil temperatures and conductivity (12), and reference values (5).

3 RESULTS

Preliminary results available at this stage are illustrated in Figures 3 to 8.

(a) Soil conductivity Soil conductivity measurements fell in the range 0.55 - 0.95 W/m°C. The average values were around 0.7 W/m°C under the floor and near the floor edge, and tended to be higher, 0.7 - 0.95 W/m°C, at the boundary about 3 m from floor edge. This pattern presumably is a result of differential wetting.

No seasonal trends were apparent on visual inspection, but there were suggestions that changes might be associated with rainfall. However the variations were not large, and would not be easy to discriminate from apparently random measurement noise of 10% or more.

(b) Floor Heat Flows In Figure 3 the 14 floor zones have been grouped into those which are on the perimeter and those which are not, and the total heat flows for those two regions and the total are plotted as the summed average flux over 10-day intervals for those two regions.

Day 0 refers to 1 January 1990, roughly mid-summer. Days No 365 and 730 are also 1 January of subsequent years.

Prior to occupation in late winter 1990 it is clear that the floor heat flow was decisively upwards in the core regions and total, whilst that in the perimeter region was also upward but much smaller. After occupation the floor heat flow switched to decisively downwards, as a consequence of the steady indoor warming. There was only minor difference in heat flows between the core region and perimeter region. As summer, autumn, and early next winter proceeded, the floor heat loss reduced steadily, beginning to increase in the perimeter regions about 100 days into 1992 (autumn). However in the core areas the heat losses did not begin to increase again until about 100 days after that (mid-winter). There are indications that a similar phase sequence may continue in the next year.

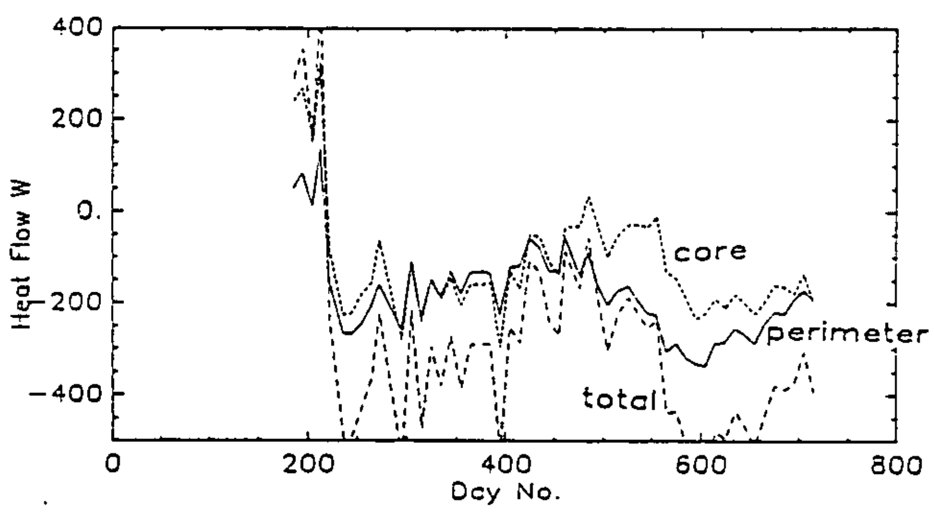

Figure 3 Floor Heat Flux Rates (10 day averages)

(c) Indoor and Outdoor Temperatures. Figure 4 shows the average indoor and outdoor temperatures recorded, also indicated as 10-day averages derived from hourly records.

Prior to occupation the mean indoor temperature typically exceeded outdoors by 4°-5°C, due solely to sunshine gains. The influence of occupation, bringing indoor temperatures up to and above 20°C, is very apparent.

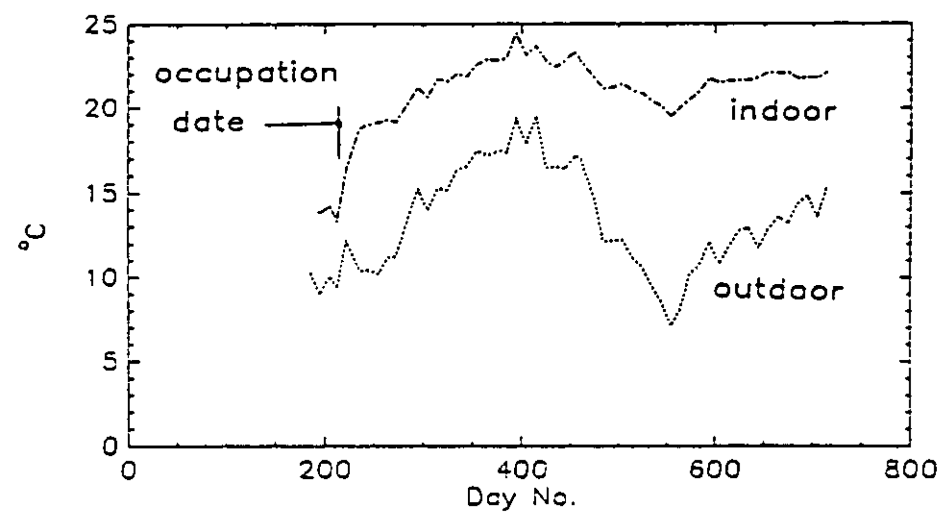

Figure 4 Indoor and Outdoor Temperatures (10 day averages)

(d) Hourly and Daily Heat Flows. Figure 5 shows an example of the hourly heat fluxes and floor concrete surface temperatures, over a 10-day period in 1992, days 1210-1220 (late winter). Of the five channels shown one is in the conservatory area, and the rest are in other perimeter and core areas. The conservatory area shows the largest daily swings in heat flux, but it is clear that the central trend in all regions is rather similar.

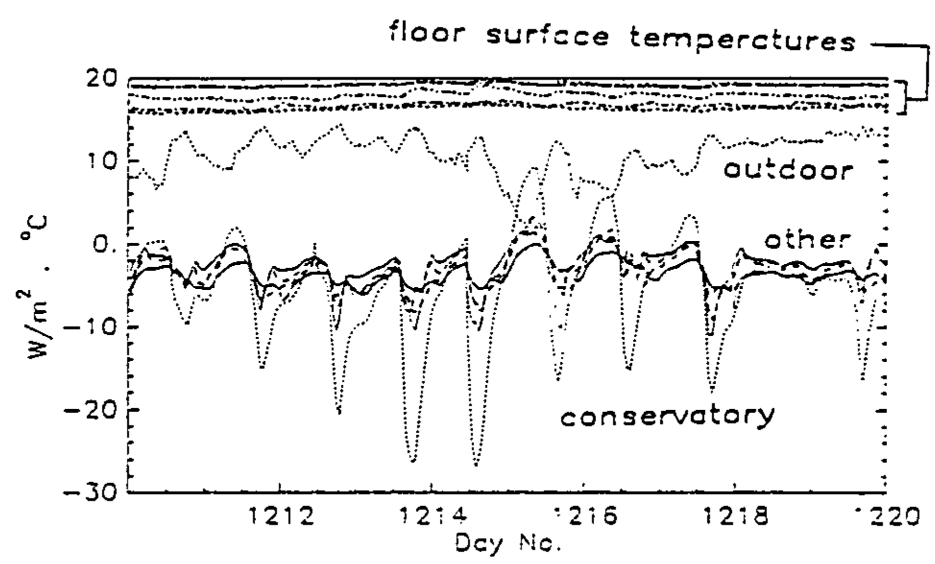

Figure 5 Hour-Average Heat Flux Values for Conservatory and Other Spaces, over 10 days (late winter)

The extreme values of heat flux on an hourly basis range from losses of about 25 W/m² to gains of about 10 W/m². This range is fairly representative of the conservatory area over most of the year, and is a little smaller (by say 20%) than that observed during the brief period before occupation and the laying of carpets on the floor, which were almost coincident.

Figure 6 presents a smoothed version of daily average floor heat flux and temperature for the same floor zones over the entire project. Days 570-580 in Figure 6 correspond to Figure 5. In this case it is the conservatory area which has the greatest heat losses. The particular conservatory area shown is a perimeter region, but note there are two other perimeter regions included in Figure 6 as well. Apparently the solar gains of the conservatory are substantially absorbed in extra losses.

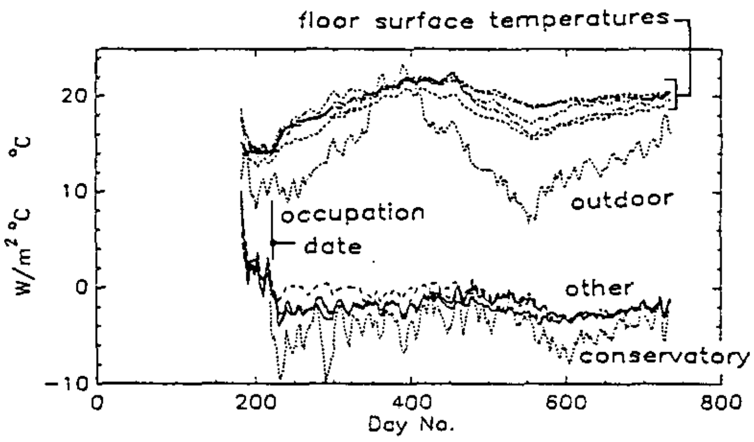

Figure 6 Smoothed Day Average Heat Fluxes and Temperatures

(e) Apparent Floor R values. Figure 7 shows the approximate thermal resistance of this floor.

In a slab-on-ground floor the heat storage capacity is very large. It has been indicated in some studies -eg, Delsante (1983) - that it may take up to five years for the heat flow pattern under a floor to equilibrate. Our data collection has not proceeded long enough to give a decisive result on this basis.

Hence Figure 7 offers only a somewhat simplistic approach to the R-value of the floor, by showing the apparent value for each 10-day period from before occupation. The trends are plausible - in winter and spring the apparent R-values are 2.5-3.0 m^2°C/W, whilst in summer the apparent values climb higher.

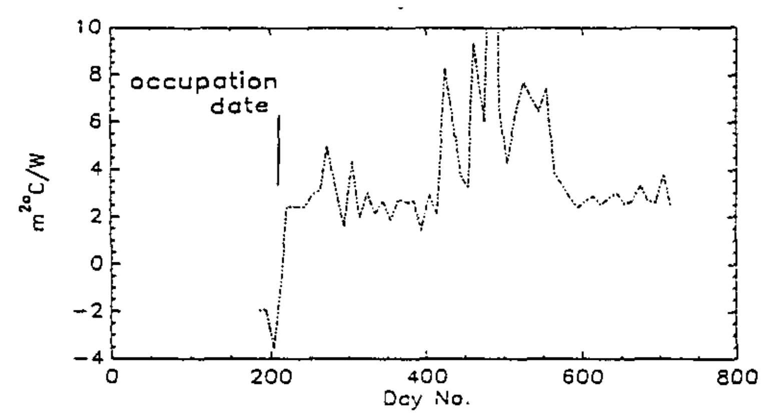

Figure 7 Approximate Floor R-Values (10-day averages)

The predicted R-value for a floor of this size, from standard handbook data such as CIBS Book A (1970) is about 1.5 -1.8 m^2°C/W. However that data is based on an undeclared assumed soil conductivity of 1.44 W/m°C. Thus the expected R-value for this floor would be around 3.3 m^2°C/W.

(f) Overall BPI. Although not part of the basic project, an attempt has been made to assess the heating efficiency of this building, in terms of the "Building Performance Index", (BPI). The BPI has been suggested as an energy performance criterion.

In principle the calculation of energy use from monthly bills, the indoor temperatures, and the accumulated degree-day (DD) values for outdoors are simple to calculate. In fact for various reasons the calculation is in practice quite difficult, but the main difficulty is that indoor temperatures always vary from the value (of 20°C) defined in the usual BPI definition. The actual variations may not be very large, but the effect on heating energy requirements is extremely sensitive to them.

In Figure 8 the BPI values for this house are calculated from the definition, on a cumulative basis. The heat usage is divided by floor area and the DD value from site records. The "All-energy uncorrected" curve includes all purchased energy, both electricity and gas, and the DD value is calculated as (+ve terms only):-

$$DD = \Sigma(16.0 - \text{mean day outdoor temp}) \quad (1)$$

The "Heating Energy Uncorrected" curve is based on an assessed part of this purchased energy which is attributable to space heating, but using the same DD value. The "corrected" curve is further modified for the effect of room over-temperature, by sliding the base temperature up when room temperature exceeds 20°C, by an amount equal to the excess.

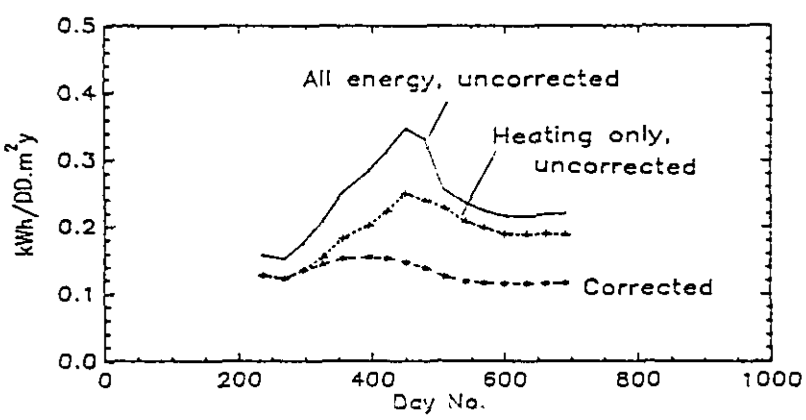

Figure 8 Approximate Cumulative Values of Energy Performance Index, B.P.I

In Figure 8, the apparent BPI values for this house, and its variation over time, are indicated with and without adjustment for variation of indoor temperatures from 20°C.

One feature of Figure 8 is the rather large effect (perhaps 50%) on the derived BPI, of an excess of only 1°-2° in indoor temperature. This reinforces that BPI may have to remain a calculated property, not readily measured. Another feature is that, when corrected as well as is practicable, the BPI for this house is estimated as about 0.11 kWh/m².yDD.

4 CONCLUSIONS

The nature of a five-year field study on slab-on-ground floor heat flows has been described. Preliminary results indicate that:-

- thermal conductivity of the wet peat soil varied over 0.6 -0.9 W/m°C.

- the apparent thermal resistance of the whole floor is rather different to that shown in many handbooks, which usually do not acknowledge soil conductivity but are commonly based on a value of 1.44 W/m°C.

  If actual details including soil conductivity are properly taken into account the resistance may be similar to that indicated by traditional formulae.

- the main part of floor heat losses take place from the immediate perimeter area, say the outer 0.5 m. Average heat loss over the outer 1.0 m was noticeably lower than that over the outer 0.5 m.

- downward heat flux at the concrete surface reached peak values of 25-30 W/m² in response to sunshine. Both peak and average values were similar for both the conservatory and normal living space areas of comparable aspect.

- upward heat flux from the concrete surface reached peak values of about 10 W/m² at night. Peak and average values were also similar between conservatory and normal living space areas. Note that for a conservatory area of around 15m², this represents a contribution of less than 200 W to night-time heating of the house.

- the overall Building Performance Index (BPI) could be derived only with low certainty, because of sensitivity to departures of indoor temperature from the standard value of 20°C. The derived value was about 0.11 W/m².y. DD.

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