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ENGINEERING APPLICATION OF HEAT FLUX SENSORS IN BUILDINGS–TECHNICAL NOTE

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Engineering Application of Heat Flux Sensors in Buildings—Technical Note

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ABSTRACT: Since 1978, new houses in New Zealand have had to achieve minimum levels of thermal insulation. A large field survey was carried out during the winter of 1983. This paper outlines the basis of the survey, the equipment used, and the measurement issues raised by the use of heat flux sensors. The results from a pilot study of 25 houses are discussed in terms of the activities that affect measurements. A comparison of calculated and "measured" *R*-values for known walls indicates a measurement "calibration" of within 10% for the equipment and analysis.

KEY WORDS: thermal insulation, heat flux transducers, field survey, *in situ* measurement, New Zealand, houses

A large-scale field survey utilizing the heat flux sensors described in a companion paper [*1*] has been carried out during the winter of 1983. This paper outlines the basis of the survey, the equipment used, and the measurement issues raised by the use of heat flux sensors.

Insulation Requirements

In 1978 the New Zealand government passed legislation requiring new houses to achieve certain levels of insulation. Provisional New Zealand Standard (NZS) 4218P:1977, Minimum Thermal Insulation Requirements for Residential Buildings, has been adopted by the 232 territorial local authorities. The basic requirements of the standard for houses without embedded heating elements are given in Table 1. Two "types" of construction were de-

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TABLE 1—*Permitted combinations where Type A construction and Type B construction occur in the same building (from NZS 4218P, 1978).*

Part of Thermal Envelope	Combinations of Minimum Standard Total Thermal Resistances, $m^2 \cdot °C/W$			
Type A roofs	1.9 2.6 3.0			
Type A walls	1.5 1.2 1.0			
Floors	0.9 0.9 0.9			
Type A roofs		1.9 2.6 3.0		
Type B walls		0.8 0.7 0.6		
Floors		0.9 0.9 0.9		
Type B roofs			1.5 2.0 3.0	
Type A walls			1.5 1.2 1.0	
Floors			0.9 0.9 0.9	
Type B roofs				1.5 2.0 3.0
Type B walls				0.8 0.7 0.6
Floors				0.9 0.9 0.9

fined, to allow for the gradual phasing out of styles (such as single-skin concrete masonry) unsuited to achieving reasonable levels of insulation.

The builder of the house is required to prove compliance with this standard through one of three methods (NZS 4218P):

(a) calculation based on a given list of thermal resistance values and suitable formulas,
(b) laboratory measurement using an approved method, or
(c) field measurement using an "approved" technique.

Standard practice is for the builders/architects either to carry out the necessary calculations themselves or, alternatively, to use the tables provided by the Building Research Association of New Zealand in its publication *A Construction Guide to Home Insulation* [2]. These calculations make allowance for any predicted thermal bridging.

Measurement Sensors

The heat flow sensors (HFSs) used have already been described [*1*]. The size of the HFS (600 by 450 mm) was chosen to ensure that a representative sample of the component being tested would be measured. Simple aluminum carrying cases provide protection, for their use in the field, for transport from the central laboratory to the field staff by normal courier methods and from house to house by the field staff.

Copper-constantan thermocouples are used for direct measurement of the temperature difference across the component. Integrated circuit temperature transducers (National Semiconductor LM3911) are used for direct measurement of the ceiling and wall temperatures.

Interior sensors are mounted inside the HFS, while the external thermocouples are mounted with masking tape, with color matching where required. Figure 1 schematically illustrates the positioning of the sensors.

Equipment

A measurement target of 100 houses over the entire country was established, and consequently the whole set of equipment had to be portable, easy to install, and rugged, but designed to leave the house unblemished. Figure 2 illustrates the sensor installation in a typical situation.

The ceiling sensor was held firmly against the ceiling by a spring-loaded stand. The wall heat flux sensor was held against the wall with a weight-loaded angle support, at a height of approximately 1 m from the floor. The

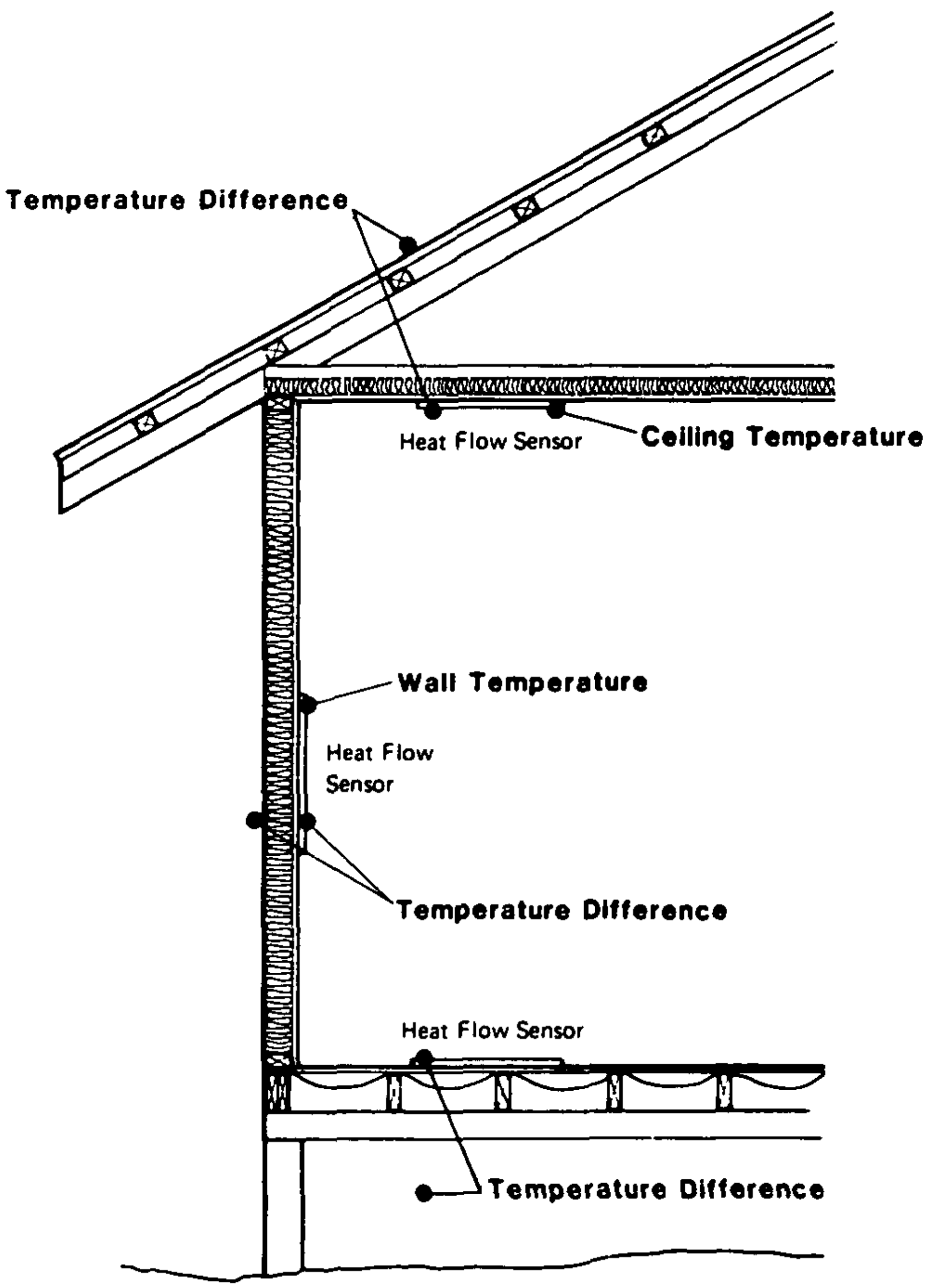

FIG. 1—*The placement of sensors for the survey of* in situ R-*values.*

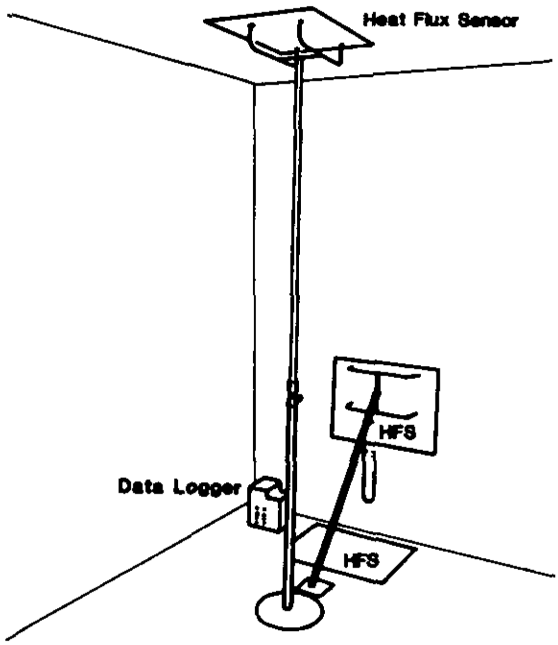

FIG. 2—*The physical installation arrangement of equipment for the survey.*

floor heat flux sensor was held by its own weight. The areas to be instrumented were checked with an infrared spot radiometer to check for anomalies, such as missing insulation or particularly poor areas. A total of five field-worker-hours was required per house for investigating, installing, and removing the equipment.

House Selection

The New Zealand Department of Statistics provided a random sample of 100 house building permits, issued between 1 April 1979 and 31 March 1982, in each of the four urban areas of interest, which were then matched to addresses by the local councils concerned. A structured mailing program was set up, with each house receiving up to three letters requesting their participation. If the occupiers were willing to allow their home to be included, they were offered either a clock-timer or an electrical plug-in thermostat (value approximately $20) as a gift.

Analysis Methods

Although a range of analysis methods appear to be available, to date analysis has been performed predominantly by the cumulative method described by Flanders [*3*], and given in Eq 1.

$$R(t) \rightarrow R$$

$$R(t) = \frac{\Sigma \Delta T}{\Sigma Q} \tag{1}$$

where

R = thermal resistance, $m^2 \cdot °C/W$,
$\Sigma \Delta T$ = summation of temperature difference, °C, and
ΣQ = summation of heat flow, W/m^2.

Other methods of data analysis have been examined, including Fourier processing and the equivalent T network [*4*], but such methods were not found to be satisfactory.

Most New Zealand houses are of timber frame construction, often timber clad although sometimes with masonry or other claddings. Such constructions usually exhibit time constants of several hours. Flanders [*3*] has shown that the method of Eq 1 converges rapidly on the *R*-value when the summation extends over an integral number of whole-day intervals. It is clear that at these intervals the stored heat in the structure approximates its value at the commencement of summation. To ensure that at least two whole-day intervals of data would be available, it was decided to monitor for approximately three days. The data logger scanned each sensor eight times per hour, recording the data on standard cassette tapes for later analysis in the laboratory.

Results and Observations

A pilot study of 25 houses was carried out during the winter of 1982 on a range of new houses in the suburbs close to the BRANZ laboratories, Judgeford, New Zealand. This not only allowed the measurement techniques to be checked but also permitted the method of selecting houses and the actual installation practices to be refined.

Calibration tests were carried out in controlled climate chambers with known *R*-value test walls and also in a yard-built house inspected during construction. The results so obtained were in good agreement with those calculated from the construction records. Figure 3 illustrates the measured versus the calculated *R*-values for a series of roofs, walls, and floors using Eq 1. The methods and values used in NZS 4214:1977, Methods of Determining the Total Thermal Resistance of Parts of Buildings, were used for the determination of the calculated *R*-values. Figure 3 indicates that the measurement error from the overall system was never greater than ±10%.

Thus, *in situ* testing, even with relatively mild winter outdoor conditions, can be expected to provide thermal resistance measurements within 10% of those expected by calculation. Variability resulting from moisture move-

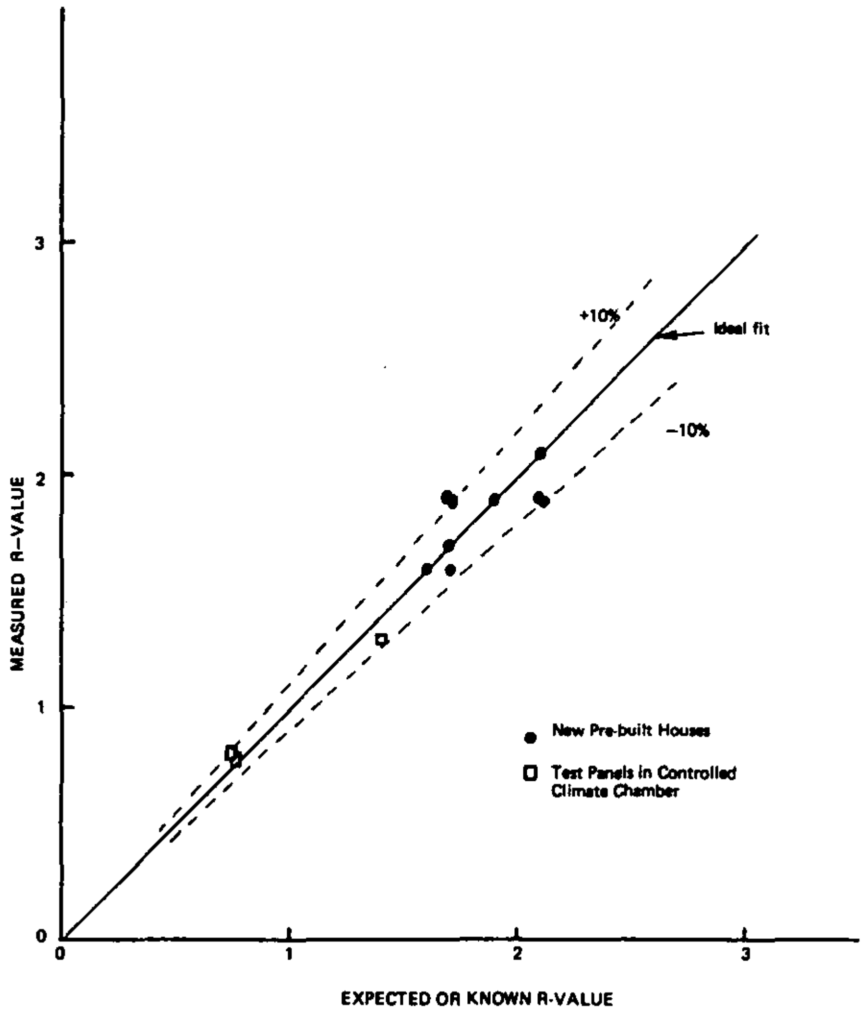

FIG. 3—*The results of the tests showing the reliability of the survey procedures.*

ments, occupant activities, or manufacturing tolerances could easily lead to larger variations.

A range of activities appears to have an effect on the measurements, including the following:

1. *Heating*—Although the measurements are made effectively under "natural" conditions, without requiring an isothermal regime, it is preferable to maintain a warm room temperature. Few New Zealand homes are centrally heated. To ensure a temperature difference across the component, a portable heater was often required. A 2-kW thermostatically controlled fan heater was used to maintain room temperature at 20°C—a temperature higher than is commonly found in New Zealand living rooms. It has been found that heat flux sensors respond extremely quickly to thermostat switching, and removal of this high-frequency component is desirable for examination of the heat flows.

2. *Climate*—For most of New Zealand, winter conditions are mild. This is a particular problem toward the end of the winter, as the building envelope may not have a sufficient average temperature difference. As the daytime temperatures increase, the inward heat flow during the day tends to balance the outflow of heat during the night. Thus, although there has been considerable flow of heat, the cumulative method cannot be used, as the cumulations tend toward zero.

Conclusions

This paper has described the use of large heat flux sensors for the purpose of a field survey of building *R*-values. The results obtained by field and controlled climate chamber calibrations for the same equipment and procedures were shown to be within 10% of the calculated thermal resistance.

The use of a copper-constantan differential thermocouple minimizes the complexity of the measurement equipment and removes the need for a reference temperature. Integrated-circuit transducers provide additional information on the temperature of the component under measurement.

The effect of thermostat control of room heating on heat flux measurement requires some filtering. Even with large sensors providing thermal smoothing, and only eight readings per hour being taken, some high-frequency filtering of the raw heat flow data is needed.

The effect of the mild New Zealand winter limits the period available for such a survey—the cumulative analysis method given in Eq 1 is unsuitable toward the end of winter.

The equipment and sensors described have been designed for ease of use by semiskilled staff. This ensures that a coherent set of measurements can be obtained regardless of the personnel installing or removing the equipment.

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