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A SURVEY OF HOUSE INSULATION

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BUILDING RESEARCH ASSOCIATION OF NEW ZEALAND

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Preface

This project was carried out by BRANZ as part of its function to evaluate the performance of buildings with respect to building codes. It was conceived as an exercise to determine how well the building industry as a whole had coped with what was a completely new, though not technically difficult, code requirement. It also represents one application of the Association's plan to reinforce its laboratory work by surveys of real, functioning buildings.

This report is aimed at research workers, code writers, building inspectors, also manufacturers and installers of insulation materials.

BUILDING RESEARCH ASSOCIATION OF NEW ZEALAND INC.
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The Building Research Association of New Zealand is an industry-backed, independent research and testing organisation set up to acquire, apply and distribute knowledge about building which will benefit the industry and through it the community at large.

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A SURVEY OF HOUSE INSULATION

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From Construction Industry Thesaurus - BRANZ edition: Full scale testing; Heat + Flowrate + Sensors; Measuring; New+Houses; Regulations; Standards; Surveys; Thermal insulation.

ABSTRACT

This report presents the results of a measurement survey, during the winter of 1983, of the thermal insulation in the roofs, walls and floors of 63 occupied houses and describes the test methods and their reliability. The method used was to datalog the output of heat flux sensors and surface temperatures, for analysis using simple averaging. Results are shown to be accurate to within ± 10%, and indicate that some 43% of houses complied with NZS 4218 P, whilst a further 30% possibly complied or were near-misses. About 10% of houses failed substantially to meet the requirement of the Standard. The mean observed R-values were roof 1.6, wall 1.4, floor 1.1 m^2C/W. A notably better insulation performance was noted in Christchurch houses compared to those in other centres.

INTRODUCTION

This report describes the procedures and results of a survey by the Building Research Association of New Zealand (BRANZ) in which roof, wall and floor insulation R-values were measured in-situ in 63 occupied houses during the winter of 1983.

The work was carried out as a follow-up to the introduction of national standards for home insulation in 1977. The aims of the survey were: to establish the levels of insulation performance being achieved in practice; to test whether the stated requirements of NZS 4218P:1977 Minimum Thermal Insulation Requirements for Residential Buildings (1977a) were being met; and to find whether any particular action might be desirable to assist the industry to achieve the requirements or if a change to the Standard was indicated.

The survey was carried out using portable data logging equipment. Building temperatures were measured by thermocouple and heat flows by specially engineered heat flux sensors to determine roof, wall and floor R-values. Only houses required to comply with NZS 4218 P were surveyed. A pilot survey during the previous winter had tested 27 houses and yielded 19 results. The main survey target was 80-100 houses, 68 were actually measured, and 63 usable results were obtained.

METHOD OF MEASUREMENT

The aim of the survey was to measure the insulation achieved with no attempt to measure any resultant energy savings. Energy savings would be expected to result from insulation, but their magnitude is affected by the different exposure to sun and wind of the buildings surveyed and by the actions of occupants. The in-situ measurement of R-values is itself not a simple task, especially under large-scale survey conditions.

Review of Possible Methods

Previous surveys of building insulation have used a variety of methods. Bastings and Benseman (1950) used a transportable guarded hot-box to measure 42 walls with R-values from 0.21 to 1.35 m^2C/W. This method was rejected for this survey as it is not suitable for use in fluctuating conditions, requires very experienced operators, and each equipment set measures only one element at a time.

Several USA surveys (e.g. Grot et al. 1982; Weidt et al. 1980) have used physical inspection, removing exterior cladding to determine the levels of insulation present. This was not considered as it is a destructive method requiring expensive restoration and co-operative home-owners. It yields only an assessment of the insulation value, not a measurement, and the assessment is dependent on the skills of the operator.

Infra-red thermography has been a popular technique in cold climates (e.g. Grot et al. 1982, Pettersson and Bengt 1980, ASHRAE/ANSI Standard 101-1981). However it was clear from a previous examination at BRANZ that the external inspection version of this method is totally unsuitable in most New Zealand conditions. The winter weather is too mild, too windy, and too wet, and indoor heating is too varied. Each of these factors alone was sufficient to render external inspection unusable. Indoor application of thermography is possible but still marginal. According to the ASHRAE/ANSI Standard 101-1981, the minimum acceptable indoor-to-outdoor temperature difference with typical instruments would be 10 ^{o}C maintained for some hours with dry surfaces, no sun, and wind less than 24 km/h, merely to discriminate between R-values of 1.7 and 2.6 m^2C/W. The cost of equipment, the need for highly experienced operators, the necessity for manual collection and analysis of data taken at frequent intervals over several days, and the difficulties in assessing the indoor surface radiative and convective conditions, ruled this method out. Alternative methods based on contact methods of measuring surface temperatures were also rejected for similar reasons.

The remaining method available is based on the use of heat flux sensors and is one of the oldest. It was used by Nicholls (1924) and by many others since, notably Flanders (1980). Investigations by BRANZ indicated that suitable heat flux sensors could be built (no appropriate heat flux sensors were commercially available). The use of data-logging equipment would allow data for several elements (e.g. roof, wall, and floor) to be recorded simultaneously, in computer-readable form for automated analysis. Sufficient sets of equipment could be provided to be operated in different centres by relatively unskilled operators. Methods of analysis of dynamically varying data have been proposed by Flanders (1980) and more comprehensively by Sherman et al. (1981). Although there were a number of technical difficulties to solve, the heat flux sensor method was selected as being the only feasible one for a survey of the proposed size.

Description of Methods Used

The installation details are indicated in Figure 1 which defines the type and location of sensors. Figure 2 illustrates the installed equipment and the manner of mounting the sensors. Only the temperatures and heat fluxes for the components in a heated building over a period of time need to be recorded, but there are a number of details which play a large part in the practicality and reliability of the measurements.

The performance of the heat flux sensors (HFS) is clearly critical. To measure in existing buildings, the HFS have to be surface mounted. The measurements obtained from heat flux sensors when surface mounted on a real structure have to be corrected slightly to indicate the heat flux which would occur in the absence of the sensor. The larger the HFS and the smaller its series thermal resistance, the smaller the error becomes, but the strength of the output signal falls with reducing sensor resistance. Large HFS were used to avoid errors due to local variations of heat flow resulting from structural bridging. The HFS sensors used (see illustration in Appendix 1) were engineered to give a satisfactory compromise between the factors of size and output signal.

The required correction is described by Trethowen (1983) and results from the local added resistance of the sensor and from edge heat spill. These corrections were typically in the range 0%-10%.

Both roof and wall R-values in this survey were initially determined as surface-to-surface values, to which the standard surface resistances of NZS 4214 Methods of Determining the Total Resistance of Parts of Buildings (1977b) were then added. The results are then directly comparable to typical rating values, such as those in NZS 4218P. It is common for the surface resistances to be included in the measurements, but this was not done here. Surface resistances are usually rather small in insulated structures (less than 10% of total resistance) but are highly variable and extremely difficult to evaluate in field conditions. They vary with local wind speed, sunshine, solar absorptance, long-wave emittance, moisture, surface texture, and surrounding geometry. Standard values for rating purposes are given in NZS 4214, and it is against that rating that the final survey results were to be assessed. An enormous amount of measurement difficulty was avoided by the decision to use surface-to-surface R-values, which were in principle all that was required.

R-values for suspended floors were determined as floor surface-to-subfloor space values. The justification for this is not as good as that for roof and walls above, but this choice was necessary to obtain usable results. Continuous concrete perimeter foundation walls were predominant, and the thermal storage capacity of these is sufficiently large that measurement over much longer than three to four days per house would have been needed. Since the heat losses through floors must pass to outdoors via subfloor perimeter walls and the ground, to derive a more complete R-value would have required very comprehensive instrumentation. The additional thermal resistance provided by foundation walls is also likely to be relatively small, especially where there are high subfloor ventilation rates. The measured R-values were not corrected to allow for foundation walls before comparison with NZS 4218P.

Measurements in each house were continued for a target period of four days. If dynamic effects are to be calculated, a minimum of three or four cycles are required of the frequency components of interest. In this case the dominant frequency of interest is one cycle per day, and therefore at least three or four days record are needed. Since in timber framed structures it is normal for the response to 24 hour periodicity to approach that for steady state, it comes as no surprise that authors such as Flanders suggest three to four days as being required for R-value estimation.

Calculation Method

The method used to derive R-values from the fluctuating field records was to use the cumulative method described in Equation 1. This method has been used widely, and is examined in detail by Flanders (1980):

$$R(t) \rightarrow R \text{ as t becomes large}$$

where

$$R(t) = (\Sigma \Delta T)/(\Sigma q) \qquad (1)$$

and q = heat flux observations W/m^2
ΔT = temperature difference observations C
R = thermal resistance m^{2}C/W and is the final converged value of $R(t)$.
t = time

This expression is simply one way of stating Fourier's Law, and is valid if and only if the heat storage within the element is the same at time t as it was at the beginning of the summation. Strictly, not only the total quantity but also the distribution of stored heat needs to recur. This condition is approached from time to time at what are in principle unpredictable times. Since the weather and the indoor climate both have very strong 24 hour periodicity, the initial storage condition can be expected to be approached once per day. Flanders has demonstrated in an extensive series of studies that this usually occurs at integral numbers of whole days, and that a useful working rule is to pick out the apparent R-values at those times. These values converge more rapidly, from smaller initial error than the centreline of the damped oscillatory function R(t).

Several cases were encountered where the mean heat flux was small compared with the daily fluctuations, and dynamic analysis is more appropriate. Analysis by fitting Fourier transforms of the measured temperatures and heat fluxes to trial single-layer slabs was carried out by the Applied Mathematics Division of the Department of Scientific and Industrial Research. Results from this method agreed well in most cases with the cumulative method of Equation 1 but have been retained only in four cases, where the cumulative method failed.

Description of Equipment

The equipment used is scheduled in Appendix 1. The main items are the heat flux sensors.

The specific features sought in these sensors were:

- sufficient physical size (600 x 450 mm) to span the (usually timber) frame spacing, so that normal thermal bridging effects would be included as part of the measurement, and the result would not depend greatly on the exact position chosen for the measurement.
- high lateral conductance, so that the surface temperature under the sensor would be properly averaged, again to avoid sensitivity to local variations of heat flow from structural bridging.
- sufficient signal output to give usable readings with the data logger measurement equipment (actual sensitivity was 25 $W/m^2.mV$).
- sufficiently low series thermal resistance to limit the effect of the sensor on the local heat flow through the element. The sensor resistance achieved was about 0.1 m^2C/W, which was 3%-10% of the expected results.
- response time constant of 5-10 minutes, so that real heat flux trends could be followed whilst avoiding the short-term transient typical of surface heat flows.

Thermocouples were mounted inside the HFS to simplify on-site procedures and to improve measurement reliability. Only the exterior thermocouple for each element had to be fitted on site, the others simply plugged in. The risk of damage to house indoor surface finishes was thereby almost eliminated by avoiding the need for adhesive tape.

RELIABILITY OF MEASUREMENTS

The reliability of measurements was established by calibration of individual equipment components, validation of the overall measurement system and analysis procedure, and provision of adequate operator training and supervision.

Equipment Calibration

Heat flux sensors: The "heater-foil" procedure described by Trethowen (1983) was adopted. This uses pairs of sensors clamped over a heater foil with known heat generation. The method in this case yielded standard deviations in the calibration constant within 1%.

Thermocouples: Calibration of the copper-constantan thermocouple wire followed BRANZ normal laboratory practice for low temperature application in a clean environment. One or two samples from each roll of thermocouple wire were forwarded to the national Temperature Standards Laboratory for calibration through the 0-100°C range. Periodic routine ice and steam point checks are made of individual thermocouple pairs. Under such mild use failures are rare, and are usually simple wire breaks.

Data-loggers/ADC: The measurement accuracy of the data logger 8 bit Analogue-to-Digital Converters and amplifier, was checked immediately before and after the survey, by comparison with a precision (1 micro volt) laboratory digital voltmeter, over the full range of both positive and negative input signals. On both occasions, about 50% of all readings showed no error and the error exceeded 1 bit in only about 10% of readings.

Overall System Validation

Tests of three kinds were carried out on the entire system. The analysis procedure was included as part of these checks.

Two panels with different R-values previously established by the guarded hot-box method were mounted in a cold chamber. Constant conditions were established and heat flows and temperatures monitored until stable. This data was recorded for a period on the equipment sets to be used in the survey, and the data obtained converted to R-values both manually and by the computer program used in the survey.

Further previously measured panels were then mounted between two controlled climate chambers, with "outdoor" and "indoor" temperatures made to vary daily over a substantial range. The pattern of these variations is illustrated in Figure 3. R-values for these panels were also derived using the methods used in the survey.

Thirdly, measurements were made as a full dress rehearsal on a yard-built house in which detailed inspections and photographic records were made throughout construction. The construction details were standard, and from experience of previous guarded hot-box tests of similar detail, the R-values for that house were considered to be known within ± 5%. The house was monitored in the builder's yard in real weather, but unoccupied.

The result of all three overall checks is illustrated in Figure 4. There was no significant difference between laboratory R-values obtained from steady state and dynamic runs. In all cases the "measured" R-values did not exceed extremes of ± 10% of the "true" value, suggesting an average error perhaps half this value. This level of accuracy was regarded as quite adequate for the purposes of the survey.

Miscellaneous Errors

In general, heat flux measurements made at or near a framing member will show higher heat flows than those made further from framing. The equipment in this survey was designed to minimise this problem. The heat flux sensors were made large and with high lateral conductance. In laboratory trials to test the effectiveness of these measures one of the 450 x 600 mm sensors was mounted on a well-insulated wall panel (about $2 m^2 C/W$) and then progressively moved through all representative positions relative to the 600 mm framing. The insulant had settled, leaving gaps of 20-25 mm next to the framing, giving rise to a fairly major thermal disturbance in that region. The indicated R-value throughout these trials varied within extremes of ±7%. In practice this variation would be small or zero in walls, where the stud spacing usually equals the sensor width and there is little variation in mounting height. However, this effect will add some further scatter to measured roof R-values.

Many thermopile heat flux sensors are sensitive to lateral temperature differences (ie, edge-to-edge). This deficiency can be avoided by the correct choice of thermopile wiring sequence, or minimised by having high lateral conductance in the sensor. The sensitivity of these sensors to temperature gradient on both major axes was examined during the above trials by rotating the sensor 180° (end-for-end). In the worst case the two readings so obtained differed by 2% for one axis, 1% for the other, when the lateral temperature difference on the wall surface was just under $1^{\circ}C$. Therefore, errors due to this effect would be less than ±1%.

Operator Training

On-site installation and checking was carried out by unskilled staff recruited for this task. Whilst the equipment was developed to be as self-contained as possible, there were two measurement factors which remained under operator influence - choice of measurement positions, and attachment of external thermocouples. The operators were also required to carry out certain routine checks designed to avoid recording failures.

All operators were given a two day training course at the BRANZ Judgeford research station, and issued with a 24 page manual detailing at elementary level the actions required at each stage of the installation process. These included preheating and scanning the selected room with hand held radiometers to reveal any thermal anomalies so that sensors were not placed at a point untypical of the element concerned; inserting roof surface thermocouples generally at least 200 mm into a cladding lap, so that true roof surface temperatures would be obtained without need for colour matching, with variations of the technique to cope with all expected roof types; attaching wall surface thermocouples using adhesive tape mounted dry, carefully dressed, and bonded for at least 100 mm, secured with long lateral tapes; and covering the measuring region with the optically-nearest of several coloured tapes. In practice, many external wall finishes were found to be similar in apparent colour to plain masking tape. Because many walls were not sun-exposed for long periods, colour-matching was less critical than for roofs. There was no further scope for operator influence.

After every installation the operators were required to test all connecting cables for short or open circuit before commencing the run, using modified bench ohm-meters.

At least two installations by each operator were observed during the survey to ensure that correct procedures were being followed. Photographs of every installation including sensor attachment, equipment location, house details and identification were returned with a full page standard report form and the data tapes of recorded measurements.

SELECTION OF HOUSING SAMPLE

Houses were selected to represent houses nominally complying with the insulation bylaw, but restricted to areas where a survey could be mounted.

This meant that houses built since 1979 in four urban centres could be included. Although this excluded provincial and rural areas, there is no a-priori reason to believe that building practices there are different from those in urban areas, with the possible exception of areas where no insulation bylaws were operating.

The housing sample was chosen by random selection of building permits by the Department of Statistics. Where the building permit had been included in the Department of Statistics regular Building Activities Survey, the Department supplied the street address, in other cases it was obtained from the issuing local authority.

It was planned to measure 25 houses in each centre. To allow for "drop-outs" approximately 100 houses were selected in each centre. Where the Department had been notified of the cancellation of the permit, this was then noted against the supplied list, and the house removed from the survey address list.

The size of the sample was a compromise between the ideal and the possible. Based on consideration of relations such as Equation 2, a sample of about 30 was desirable in each area surveyed.

$$P_{95} = p \pm 1.96\sqrt{\frac{pq}{n}} \qquad (2)$$

where
P_{95}= range in which there is 95% confidence that true pass rate will lie.
p = observed proportion of sample that "pass"
q = observed proportion of sample that "fail" i.e. (1-p)
n = number in sample

The use of Equation 2 shows that the sample confidence error for sample size of 50 to 100 decreases from 6.2% to 4.4% when the "pass" rate is 95%, and from 14% to 10% when the "pass" rate is 50%. Thus a total sample size of 50-100 is clearly adequate for the survey as a whole. It was calculated that a number within this range was logistically possible. This number is a little small for high confidence resolution of between-centre differences, and for the achieved sample size of about 16 per centre, the sample confidence error is 11-24% depending on the observed pass rate. This means that apparent regional differences may need careful review before being accepted.

Table 2 gives a summary for building permits issued 1980-1982 in the four centres: Auckland (41.7%), Wellington (9.2%), Christchurch (10.4%) and Dunedin (2.4%). The total number of building permits issued in urban areas was 58.3%. These four urban areas included 37.1% of the total.

Closer examination of the number of building permits for these four centres by council shows a wide variation in the numbers issued, with those councils on the periphery of the urban area normally issuing the largest numbers of permits.

Survey Procedure

The survey procedure is illustrated in Figure 5.

Table 3 gives the response rate by city. Of the 363 addresses available for the survey, it was only necessary to use 250 in the mailing programme. Letters could not be delivered to 20 of these, leaving 230 valid addresses. One hundred and thirty-three replies were received, giving a response rate of 58%. Only 41 house occupiers declined to participate in the survey, while the remaining 92 requested further information. After exclusion of unsuitable houses and house occupiers deciding not to participate in the actual measurement programme, a total of 68 houses from this group were tested and yielded 63 usable sets of data for analysis including five from tests repeated following initial equipment malfunction.

The field measurement stage of the survey ran for 18 weeks, with the first installation on 22 June 1983 and the last installation removed on 18 October 1983.

The statistics of the sample of houses finally measured are given in Figures 6 to 9. Examination of these statistics has produced no indication that the sample was in any way unrepresentative of houses built in the period under review.

Survey Results

The insulation types found and the measured R-values are discussed below.

Insulation Types

This study was not intended as a survey of the various insulation materials available in New Zealand, but the materials encountered are of some interest and are detailed in Table 4. In the case of roofs and floors, field staff were often able to verify the material used, but for walls the materials are those stated by the householder. "Unknown" insulation materials are cases where verification was not possible by either of these means.

Measured R-values

A complete summary of the R-values derived from the survey is shown in Table 5 and illustrated in Figure 12. Missing values are indicated by asterisks, and values for slab-on-ground concrete floors are indicated by "C". Slab-on-ground floors are not measurable within reasonable time-spans, but because of their known behaviour they can be assumed to comply with the standard (this may not be true for sites where ground-water levels are high).

The results in Table 5 and Figure 12 show clearly that the level of insulation achieved in the Christchurch region is markedly higher than in other centres, and in all three components - roof, walls, and floors. Figure 12 shows that 10 of 14 cases which exceed the equivalent of a Type A/Type A (roof/wall) performance are located in Christchurch. Not one of the 11 cases falling short of the Type B/Type B equivalent is in Christchurch.

A summary of R-values derived from the pilot survey is shown in Table 6. The mean results are not markedly different from the main survey.

An example of the temperature and heat flux record obtained during test is given in Figure 10. The heat storage effects associated with periods of warming up and cooling down are readily apparent.

The progressive R-value computation for one house is shown in Figure 11. These curves should be regarded as a damped oscillatory approach toward the final results. Dotted on these curves are lines joining points of integral 24-hour intervals, following Flanders suggested method for R-value determination. It can be seen that those lines and the decaying centreline of the damped oscillatory curves are convergent, with the convergence being slowest in the case of the floor where greater storage influences are at work.

Relation to Standards

NZS 4218P provides for different trade-off levels between roof and wall insulation, and within defined limits lower wall R-values can be compensated by higher roof values. The Standard also provides, by classification into type A & B construction, for the degree-of-difficulty to fit sufficient insulation. The Type A/B classification of a completed building requires full information about the internal construction detail, which it is not always possible to determine by non-destructive inspection. For administrative simplicity the Standard permits the trade-offs to occur only in three steps, with rigid limits, but to assess the real value to building and occupants, it is appropriate to interpolate and extrapolate these rigid limits. The trade-off in NZS 4218P was based on an equal heating energy criterion assuming continuous winter heating, and including a fixed floor-ceiling temperature difference of 5°C. It is quite easy to fit such a function approximately through the points defined in the Standard. This has been done in Figure 12, and the curves shown represent equal heating energy requirements for Type A/Type A, Type A/Type B, Type B/Type A, and Type B/Type B roof/wall pairs respectively, to those permitted in NZS 4218P.

Applying the limits set in NZS 4218P (Table 1), to the results, 9 houses unquestionably pass all the requirements, whilst 19 clearly fail. The remaining 35 require classification into Type A or B before their status is clear. When these steps are taken it is found that there were 14 houses insulated to the equivalent of Type A/Type A, whilst 11 houses fell below the Type B/Type B equivalent. A further 8 failed to meet the floor requirement. The remaining 30 houses were grouped into 13 identifiable as Type B and therefore complying, and 17 which could not be identified. From this it may be seen that 27 houses complied with the intention of the standard, 17 were inconclusive and 19 failed.

A particular feature is that there is no evidence that lower wall R-values are being compensated for by higher roof R-values. The wall and roof results are uncorrelated. The industry has thus not demonstrated an ability to meet the terms of the permitted trade-off.

The measured R-values for suspended floors are illustrated in Figure 13, which separates the results into "sheltered" and "exposed" subfloor categories. The "sheltered" cases are those with continuous foundation perimeter wall excluding wind entry, and the "exposed" cases are the remainder. The measured R-values reported for suspended floors in this survey are for the floor deck only, as shown in Figure 1. This is significant, as the overall indoor-outdoor R-value will be slightly greater than our reported value for "sheltered" floors, because the perimeter foundation wall will add some small further thermal resistance. However no such addition can be expected for the "exposed" cases, and so the real difference between groups in Figure 13 will be even more marked than that shown. This illustrates that without exception all "exposed" subfloors had R-value less than the minimum 0.9 m^2C/W called for in NZS 4218 P, whilst at least 75% and probably over 90% of the "sheltered" cases complied, often with ample reserve.

FACTORS AFFECTING RESULTS

A sizeable number of the structures apparently failed to meet the specified levels, and it would be useful to know whether this results from materials, or workmanship, or something else. Although some point-to-point variation in R-value is to be expected, the radiometer pre-screening should have prevented consequent errors from selection of non-typical segments of structure.

In its programmes of industry testing and of background research, BRANZ experience has been that the dominant reason for structures failing to meet superficially expected R-values has been thermal bridging or the presence of edge gaps in insulation. Apparent performance loss up to 2:1 from these causes is quite feasible. Similar experiences are commonly reported overseas. In general the higher the target R-value, the more sensitive a structure is to these effects, but if thermal breaks are present in the structure the discrepancies substantially disappear. Calculations can be done quite accurately to allow for these effects if the full construction details are known.

By comparing photographs (where available) of insulation details with measured results, it was noted that about one in five foil-insulated floors had foil pulled too taut and showed low R-values. About an equal number were in exposed subfloor spaces and showed even lower R-values. Case W3 was an extreme one, exposed to wind and with foil pulled almost taut, and giving a measured R-value of 0.5 m^2C/W, not much higher than an uninsulated floor. In another case (A14) poor fitting of foil combined with an exposed perimeter gave a startlingly low R-value of $0.2m^2C/W$.

Some 40% of roofs had R-values substantially lower than might be expected from a general description. Approximately equal proportions of these were the result of poor installation, had thinner insulation than normal or were unidentified. Using the background information mentioned above, it was clear that those roofs with thinner insulation had suffered more from the thermal bridging created by exposed structural timbers than from simple lack of insulant. Therefore the low R-values were attributed more to installation details than to materials.

The most common apparent failure was from untidy fitting of the insulant. Folded or buckled batts, tucked edges, and edge gaps are commonly visible in photographs. These features allow warm air streams to spill out from the ceiling area. In blown installations the principal fault was uneven application, especially failure to fill the "shadowed" area behind ceiling framing at installation time. Particularly interesting are cases such as A13, where the installer with great diligence had cut and fitted every batt down between dwangs. The thermal bridging by those dwangs has kept the measured roof R-value down to 1.1 m^2C/W, whereas neat fitting of the same batts over the dwangs as in case C7 would have been cheaper to install and would have achieved a much higher R-value, over 2.0 m^2C/W.

Clearly showing up in some site records, though not part of the survey measurement, was the failure to ensure that the whole envelope was insulated where there were changes in ceiling line. Walls to attic rooms were quite often not insulated, as were edge areas to ground floor ceilings with attic rooms above that did not extend all the way to the ceiling edge.

CONCLUSIONS

A survey conducted by BRANZ has made in-situ measurements of the thermal resistance (R) values in 63 occupied houses, issued with building permits April 1979-March 1982 in four urban regions - Auckland, Wellington, Christchurch, Dunedin.

The principal conclusions drawn from this study are:

1. In-situ R-value measurements of roof, wall, and floor can to be made during winter with portable, non-damaging, equipment, with an overall accuracy within 10%.

2. The R-values measured ranged from an extreme low of 0.2 m^2C/W to a maximum of 2.7 m^2C/W. The mean R-values were as below, with standard deviation of 0.4-0.5 in all cases.

	No. of cases	Roof	Wall	Floor
			R Value m^2 C/W	
Auckland	(17)	1.7	1.2	1.0
Wellington	(17)	1.6	1.2	0.9
Christchurch	(15)	2.0	1.7	1.5
Dunedin	(14)	1.1	1.5	1.0
	mean	1.6	1.4	1.1
Mean result from pilot survey (14)		1.8	1.4	1.0
(Typical uninsulated Value)		0.4	0.3	0.3)

3. Because different categories are prescribed in the insulation standard (NZS 4218 P) it is not possible to classify all results positively as "pass" or "fail" in terms of the standard.

   However at least 43% (27 of 63 houses) complied with the intention of NZS 4218P and a further 27% (17 of 63 houses) could have complied if roof and/or wall were classified as Type B.

   The remaining 30% (19 houses) were divided between 20% (13 houses) which achieved insulation levels that very probably could have complied given improved installation techniques, and 10% (6 houses) which failed very substantially to approach the requirements.

4. No evidence could be found that lower wall R-values had been matched with higher roof R-values, as required by NZS 4218 P.

5. Where there were continuous perimeter foundations, almost all foil-insulated suspended floors were found to have R-values exceeding the Standard (R=0.9), some substantially so. The mean value was 1.1 m^2C/W.

   Where the subfloor space was not fully enclosed, no foil-insulated suspended floor reached 0.9, and the mean R-value was 0.55 m^2C/W.

6. Where construction details could be established, the measured R-values were consistent with those expected from BRANZ calculation. In at least a significant proportion of the 20% group, the low R value was therefore attributed to be a consequence of the installation details rather than of the materials used.

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PERMITTED COMBINATIONS WHERE TYPE A CONSTRUCTION AND TYPE B CONSTRUCTION OCCUR IN THE SAME BUILDING

Part of thermal envelope	Combinations of minimum standard total thermal resistances (m^2 °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

Table 1: Reproduction of Table 3 from NZS 4218P, 1977

Type A = refers to structure types where cavities are present to enable satisfactory insulation

Type B = refers to all other types (e.g. concrete masonry, solid plant, etc).

Area	No.	% of urban	% of total
Northern Auckland	2588	12.1	7.0
Western Auckland	1784	8.3	4.8
Central Auckland	1038	4.8	2.8
Southern Auckland	3535	16.5	9.6
Total Auckland	8945	41.7	24.3
Lower Hutt Valley	539	2.5	1.5
Upper Hutt Valley	211	1.0	0.6
Porirua Basin	588	2.7	1.6
Wellington	642	3.0	1.7
Total Wellington	1980	9.2	5.4
Christchurch	2229	10.4	6.1
Dunedin	511	2.4	1.4
Total 4 Urban Areas	13,665	63.7%	37.1%
Total NZ	36,791		
Total Urban Areas	21,457	100%	58.3%

Table 2 Building permits by selected geographic region 1980-1982

	Mailing Programme					Measurement Programme
City	Available	Posted	Returned Not built etc	Valid Houses	Replies	Satisfactorily Completed
Auckland	91	75	7	68	34	17
Wellington	88	73	8	65	30	17
Christchurch	92	56	1	55	35	15
Dunedin	92	46	4	42	33	14
TOTAL	363	250	20	230	132	63

Table 3: Mailing programme and response

	LOCATION														
	ROOF					WALL					FLOOR				
Insulation	A	W	C	D	Sum	A	W	C	D	Sum	A	W	C	D	Sum
Macerated paper	6	5	7		18										
Blown Fibreglass	4				4										
Fibreglass batts	7	11	8	13	39	8	12	14	10	44					
Foil						6	4			10	13	13	6	12	44
Other									2	2					
Concrete slab-on-ground											4	4	6	1	15
Unknown						3	1	1	2	7			3	1	4
None		1		1	2										
	17	17	15	14	63	17	17	15	14	63	17	17	15	14	63

A = Auckland
W = Wellington
C = Christchurch
D = Dunedin

Table 4: Insulation types

CITY	Case No	ROOF	WALL	FLOOR	CITY	Case No	ROOF	WALL	FLOOR
Auckland	1	2.5	0.9	1.1	Wellington	1	1.4	1.7	0.5
Auckland	2	2.4	0.7	1.8	Wellington	2	0.6	*	1.0
Auckland	3	1.5	0.8	1.0	Wellington	3	1.3	1.2	0.8
Auckland	4	2.7	0.6	0.6	Wellington	4	1.8	1.2	1.2
Auckland	5	0.8	0.8	1.4	Wellington	5	1.0	1.2	*
Auckland	6	1.4	1.3	*	Wellington	6	0.8	1.4	1.1
Auckland	7	2.3	1.4	*	Wellington	7	1.8	0.7	1.0
Auckland	8	2.3	0.7	C	Wellington	8	1.1	1.0	C
Auckland	9	1.6	1.6	1.0	Wellington	9	2.4	0.7	1.3
Auckland	10	1.5	1.4	C	Wellington	10	2.4	1.1	C
Auckland	11	1.4	1.8	C	Wellington	11	2.5	2.5	C
Auckland	12	1.3	1.3	0.9	Wellington	12	1.5	0.7	0.9
Auckland	13	1.1	1.7	0.8	Wellington	13	2.1	0.8	0.9
Auckland	14	0.8	1.4	0.2	Wellington	14	0.6	1.4	0.6
Auckland	15	1.3	1.2	1.4A	Wellington	15	2.5	0.8	0.6
Auckland	16	2.1	1.0	C	Wellington	16	1.8	1.0	C
Auckland	17	1.4	2.1	0.8	Wellington	17	1.5	1.4	0.9
	MEAN	1.7	1.2	1.0		MEAN	1.6	1.2	0.9
Christchurch	1	2.0	1.1	*	Dunedin	1	*	1.0	1.2
Christchurch	2	2.1	1.7	*	Dunedin	2	*	1.5	0.8
Christchurch	3	2.0	1.3	C	Dunedin	3	*	1.1	1.2
Christchurch	4	2.0	2.0	*	Dunedin	4	0.9	1.5	C
Christchurch	5	2.6	1.3	*	Dunedin	5	0.4	1.5	0.5
Christchurch	6	2.3	2.0	C	Dunedin	6	1.4	1.9	1.7
Christchurch	7	1.3	1.7A	*	Dunedin	7	2.0	1.8	1.8
Christchurch	8	2.4	1.7	0.9	Dunedin	8	1.6	2.2	1.8
Christchurch	9	1.7	2.4	C	Dunedin	9	1.6	1.1	0.4
Christchurch	10	2.3	1.3	C	Dunedin	10	1.1	2.3	0.4
Christchurch	11	2.0	1.7	C	Dunedin	11	1.2	1.3	0.7
Christchurch	12	2.0	*	C	Dunedin	12	0.8	1.4	0.8
Christchurch	13	2.0	2.4	2.1	Dunedin	13	0.8	1.3	0.6
Christchurch	14	1.6	1.3	1.5	Dunedin	14	0.6	*	*
Christchurch	15	1.7A	2.4A	C					
	MEAN	2.0	1.7	1.5		MEAN	1.1	1.5	1.0

Notes:-

'*' Individual result could not be obtained.

'C' Concrete slab-on-ground floors are indicated by a "C". These were not measurable, but can be assumed to comply.

'A' R-values calculated by Applied Mathematics Division, DSIR by a dynamic analysis method.

Table 5: Summary of Measured R-values - Main Survey

	Case No.	Roof	Wall	Floor
Prebuilt houses	1	-	1.7	1.2
	2	1.9	1.9	1.0
	3	2.1	1.9	1.0
	4	1.9	1.6	0.6
Occupied houses	1	1.9	1.6	-
	2	1.6	0.8	0.8
	3	1.9	1.4	1.2
	4	0.4	-	1.0
	5	2.2	1.2	0.9
	6	2.6	1.6	1.3
	7	-	1.4	0.8
	8	2.4	0.9	C
	9	1.6	1.6	0.4
	10	2.5	2.2	2.3
	11	1.5	0.4	-
Mean	(14)	1.8	1.4	1.0

Table 6: Summary of measured R-values from Pilot Study

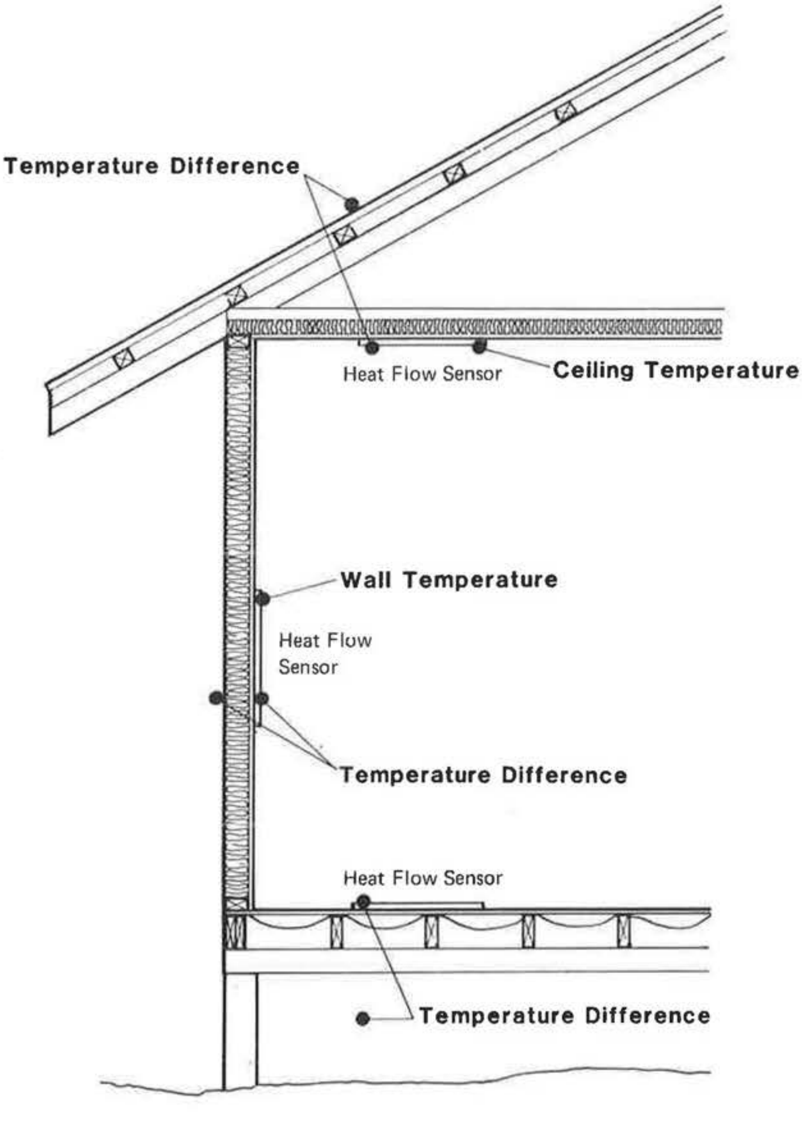

Figure 1 : Simplified view of sensor placement

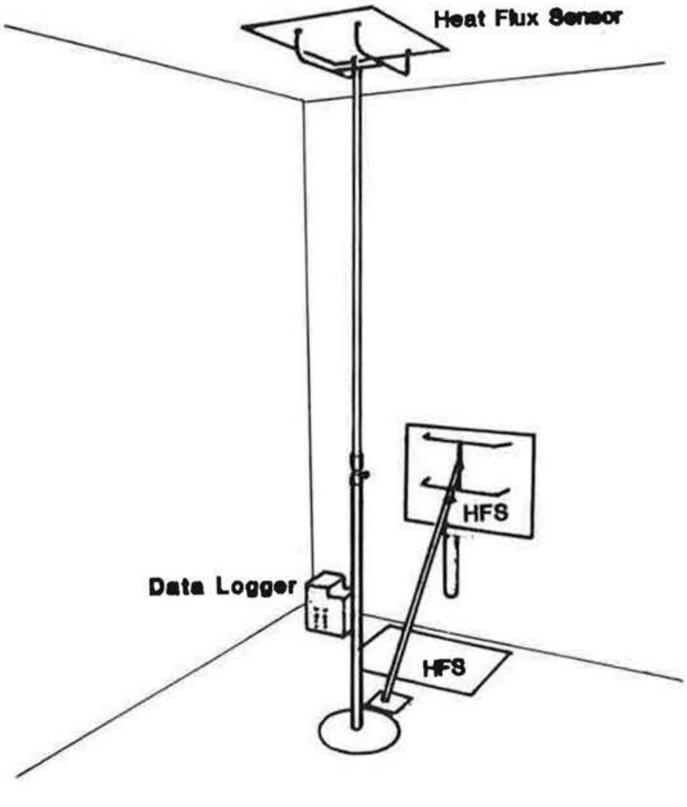

Figure 2 : Heat flow sensors in a representative installation

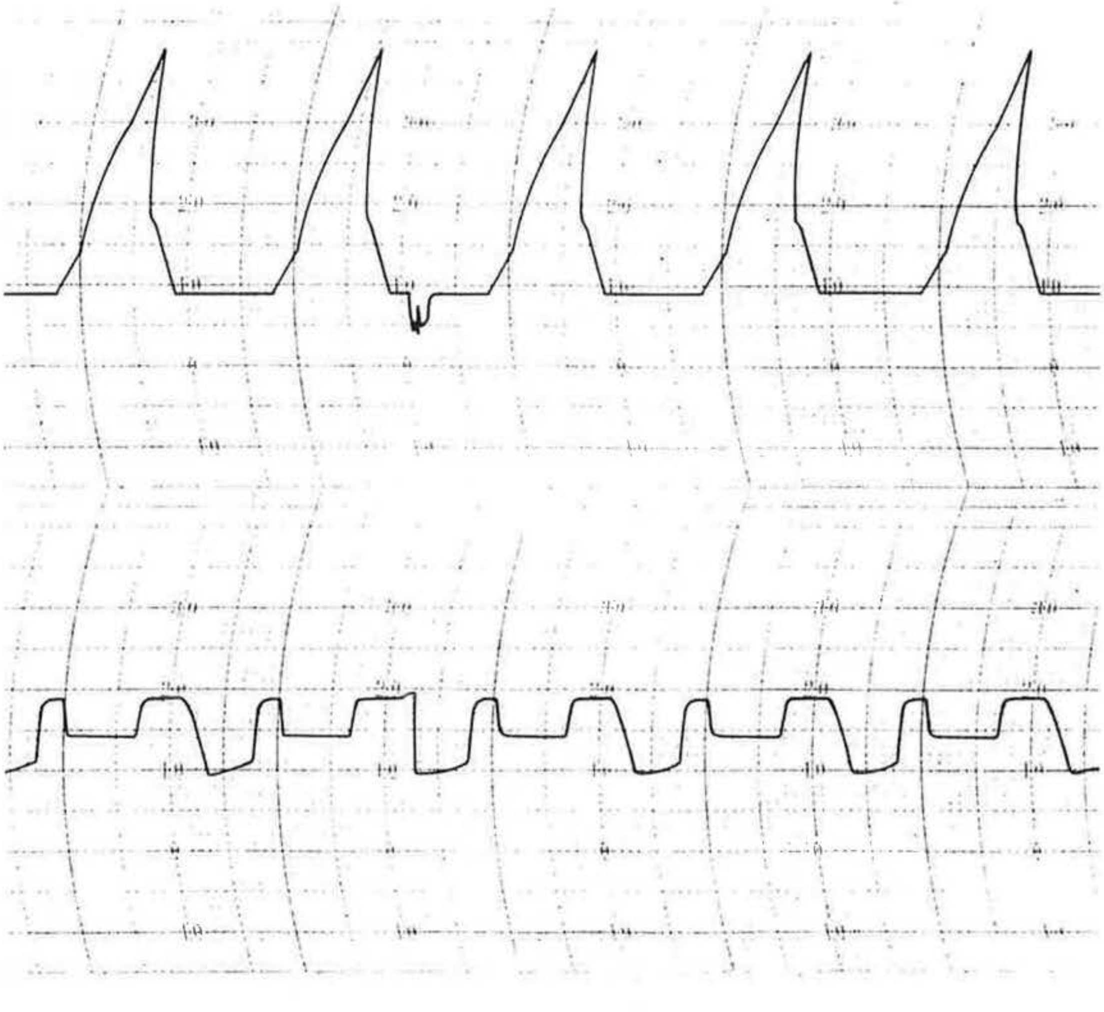

Figure 3: One of the temperature fields imposed on panels for R-value measurement by Insulation Survey method, controlled climate chambers

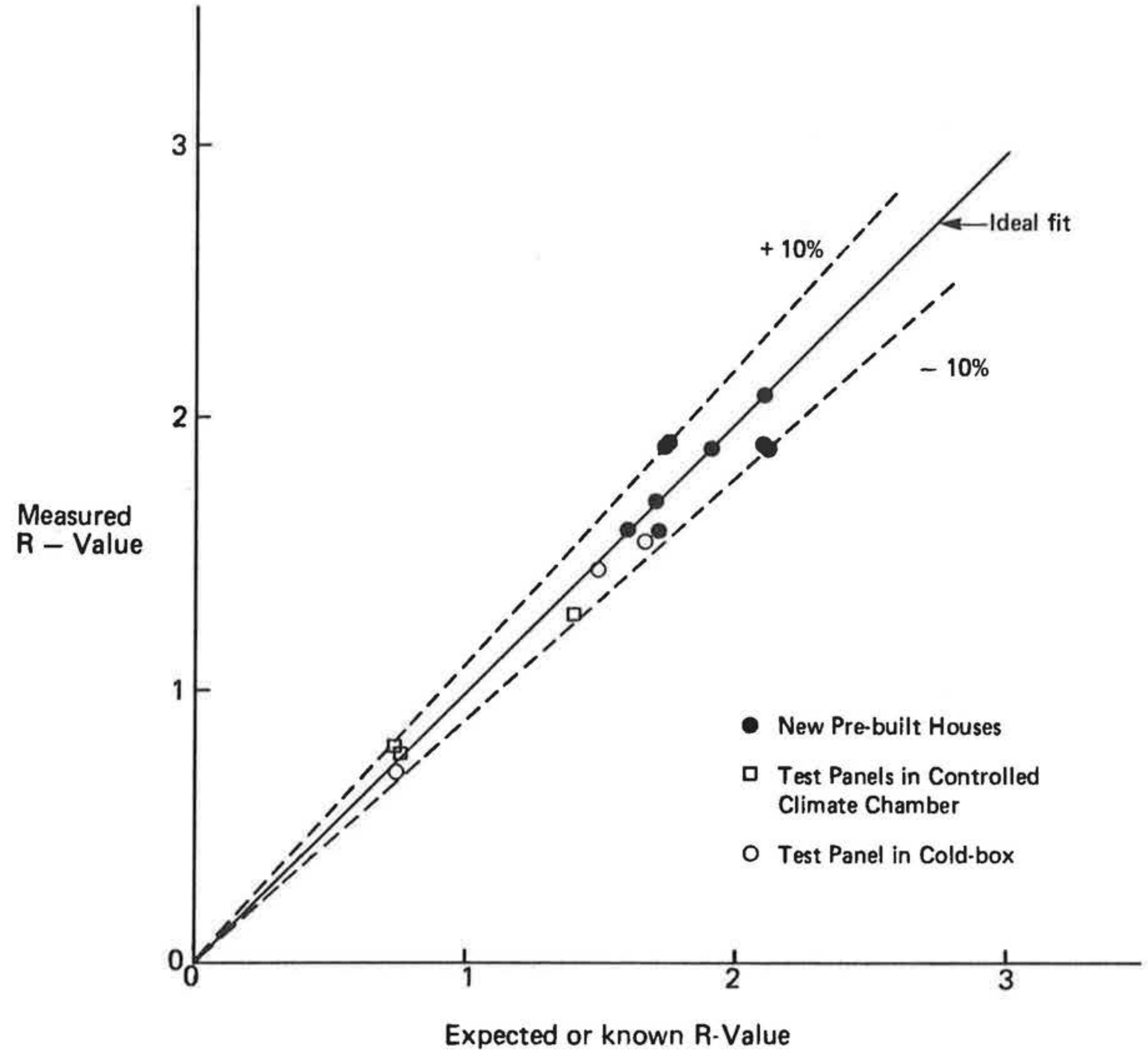

Figure 4: Expected or known r-value. 'Results of tests showing reliability of the survey procedures

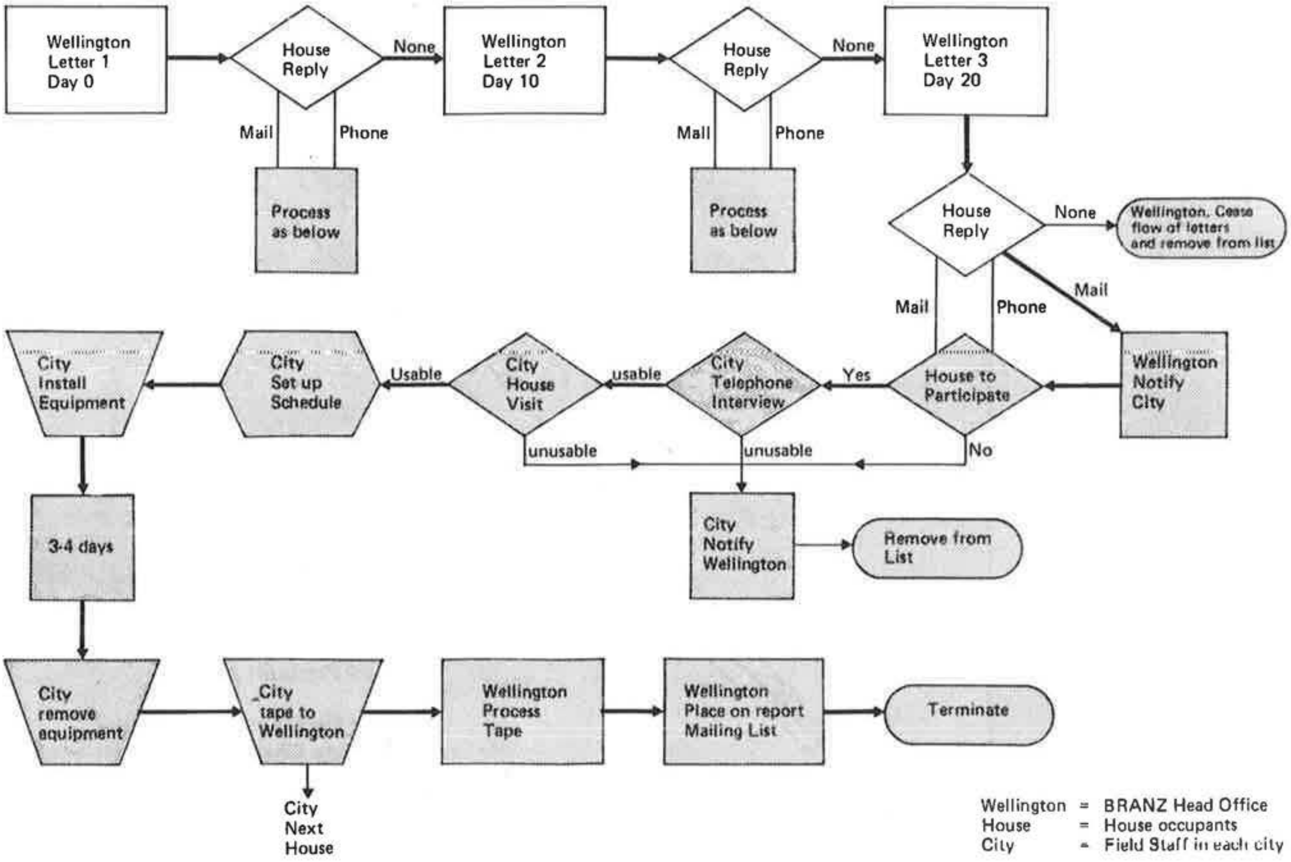

Figure 5: Flow chart of the mailing and measurement programme for the 1983 survey

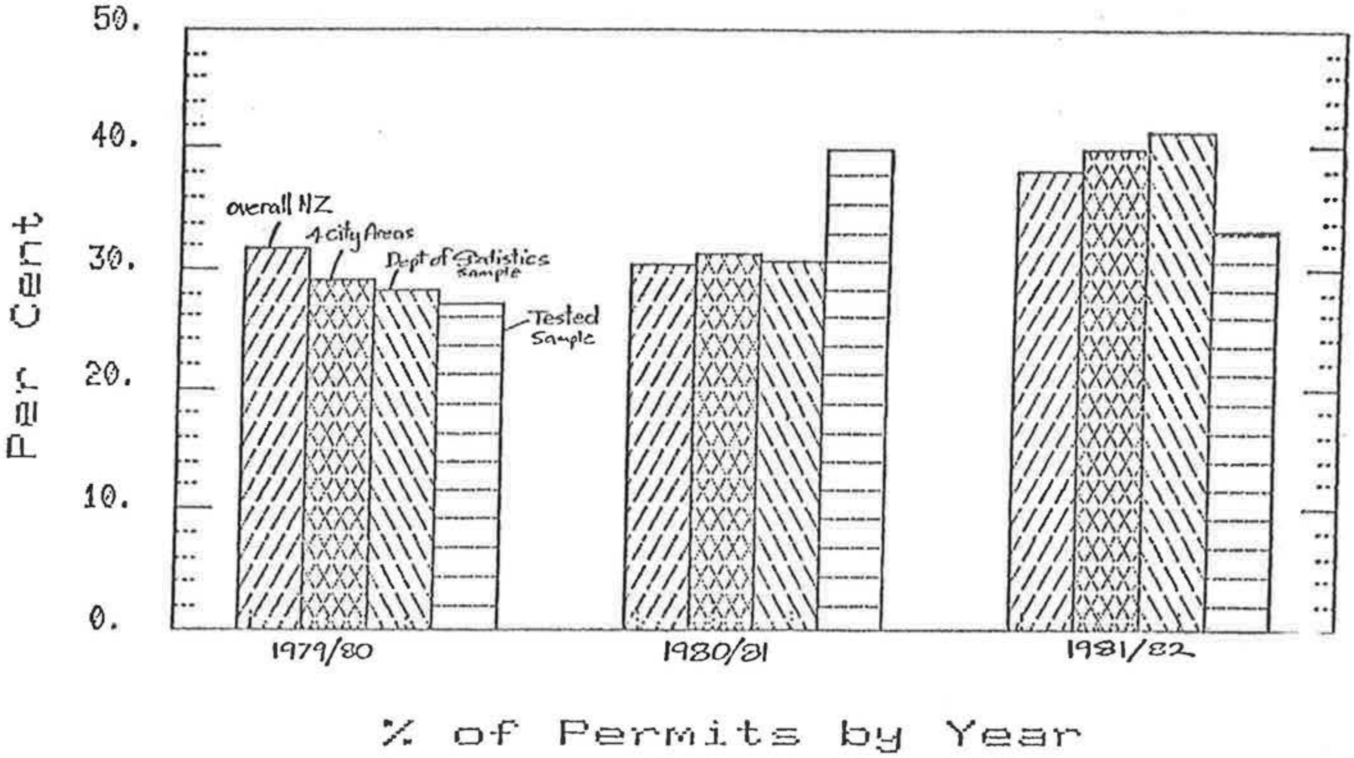

Figure 6: Proportion of permits issued by year

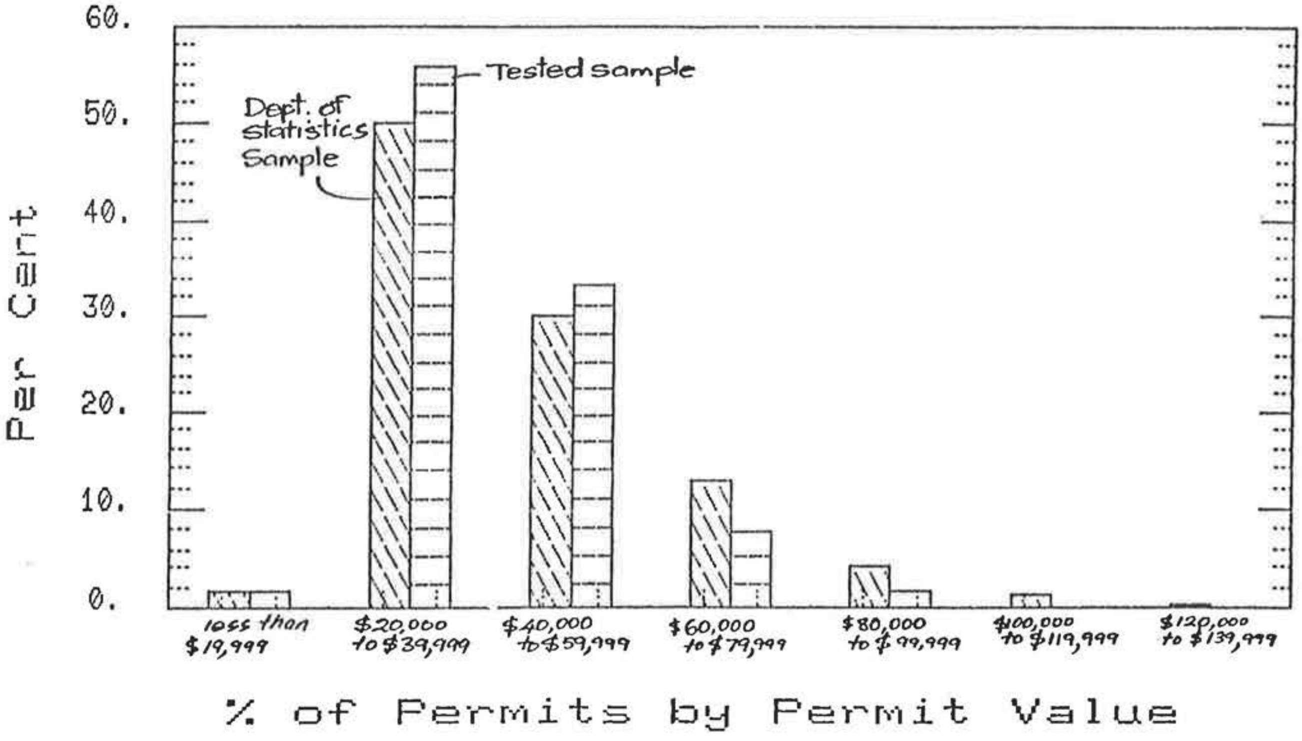

Figure 7: Percentages of permits by permit value

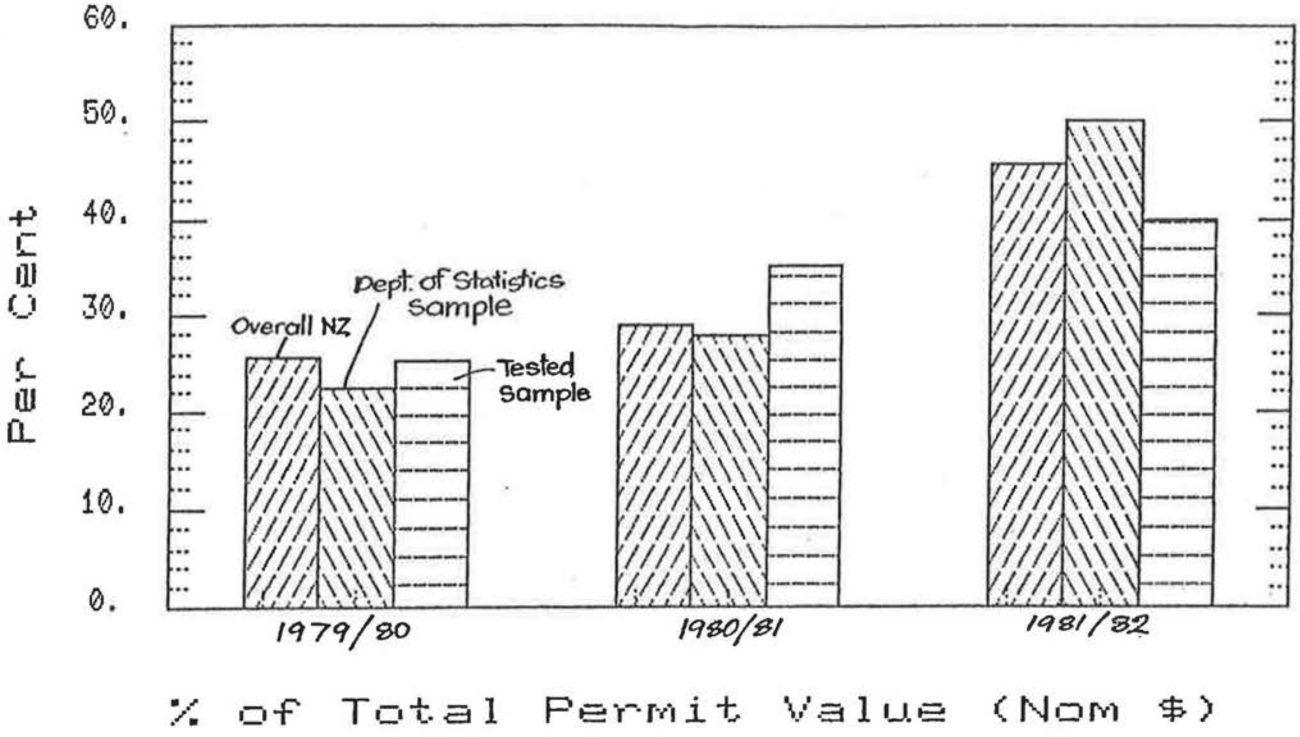

Figure 8: Proportion of total permit value by year (nominal dollars)

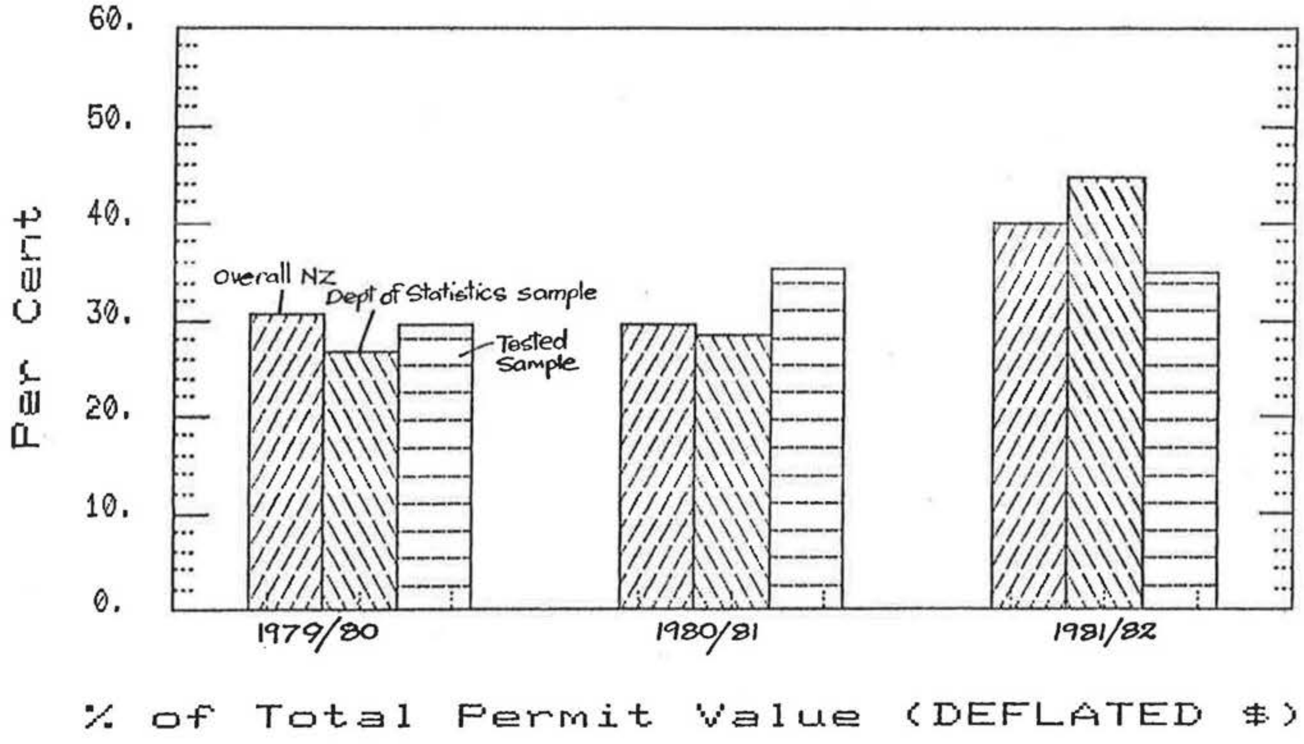

Figure 9: Proportion of total permit value by year (deflated dollars)

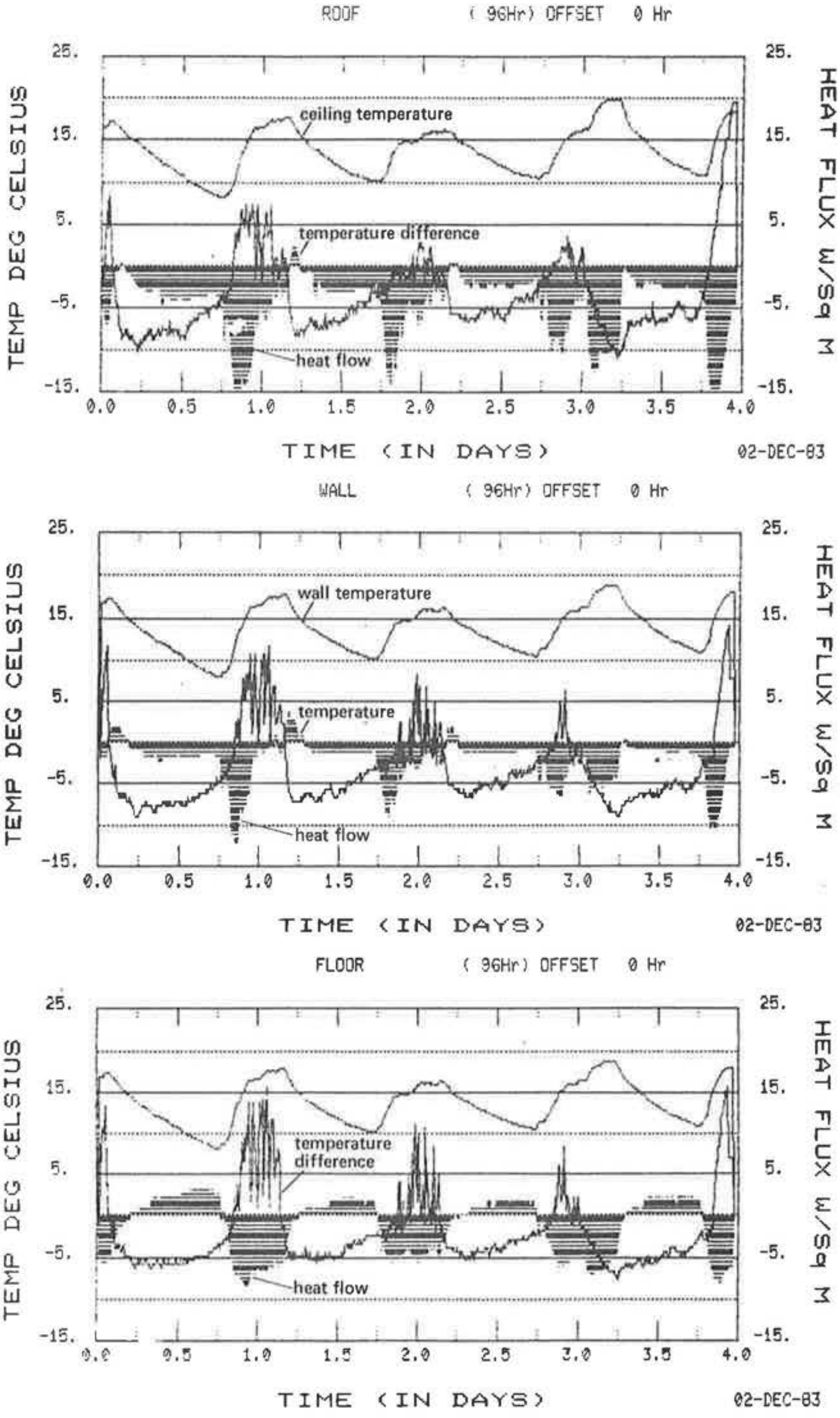

Figure 10: Recorded data for a sample house

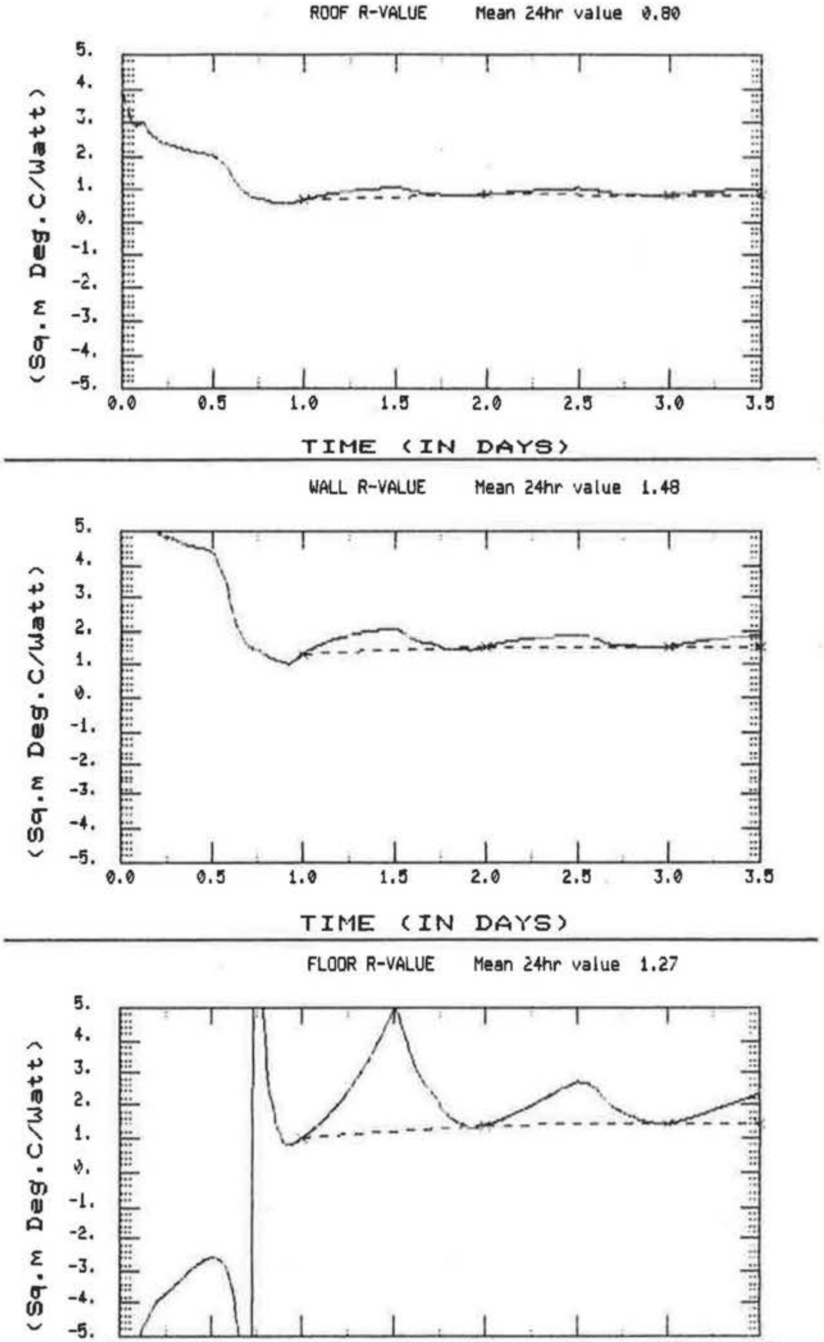

Figure 11: Derived R-values for a sample house

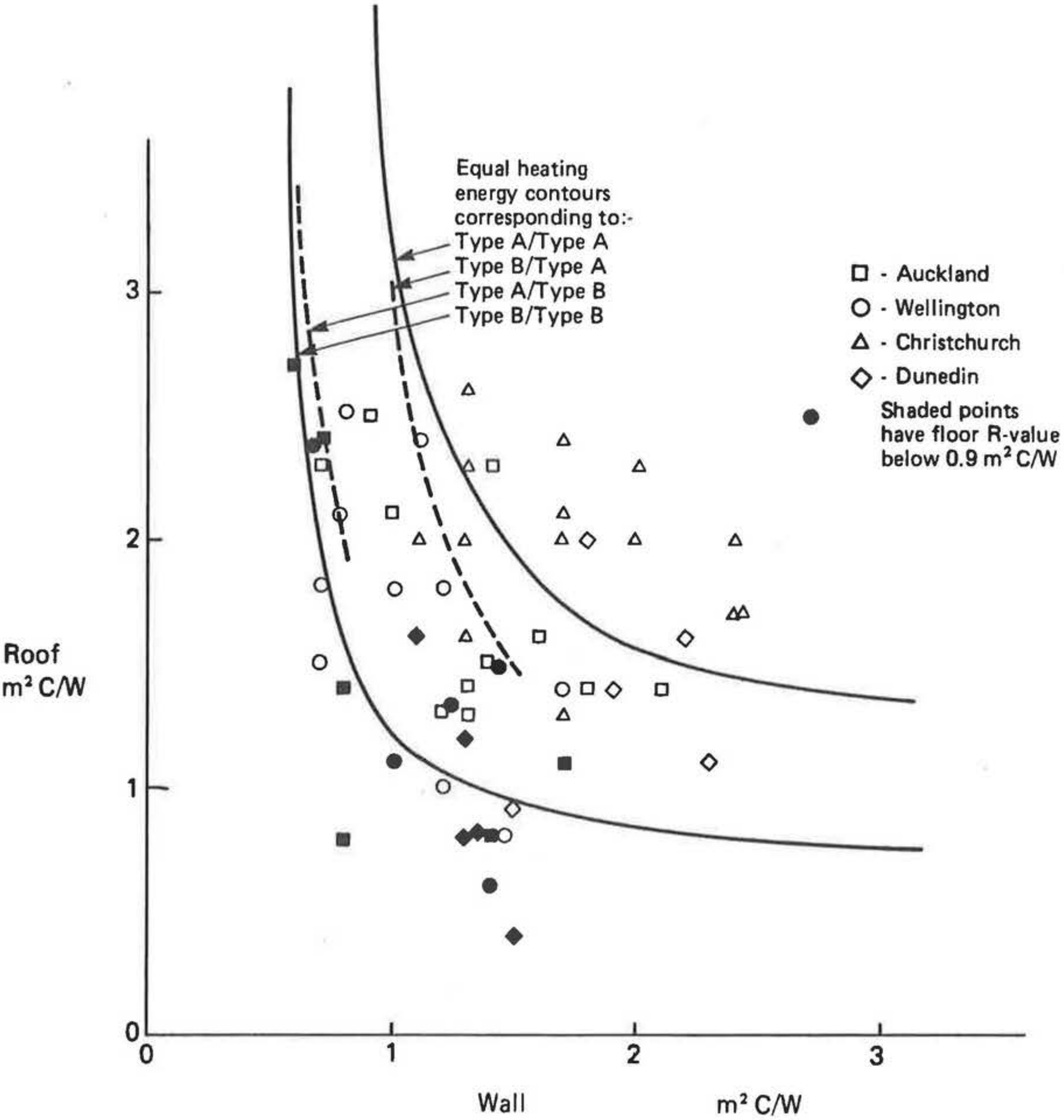

Figure 12: Measured R-values showing relation between roof and wall performance

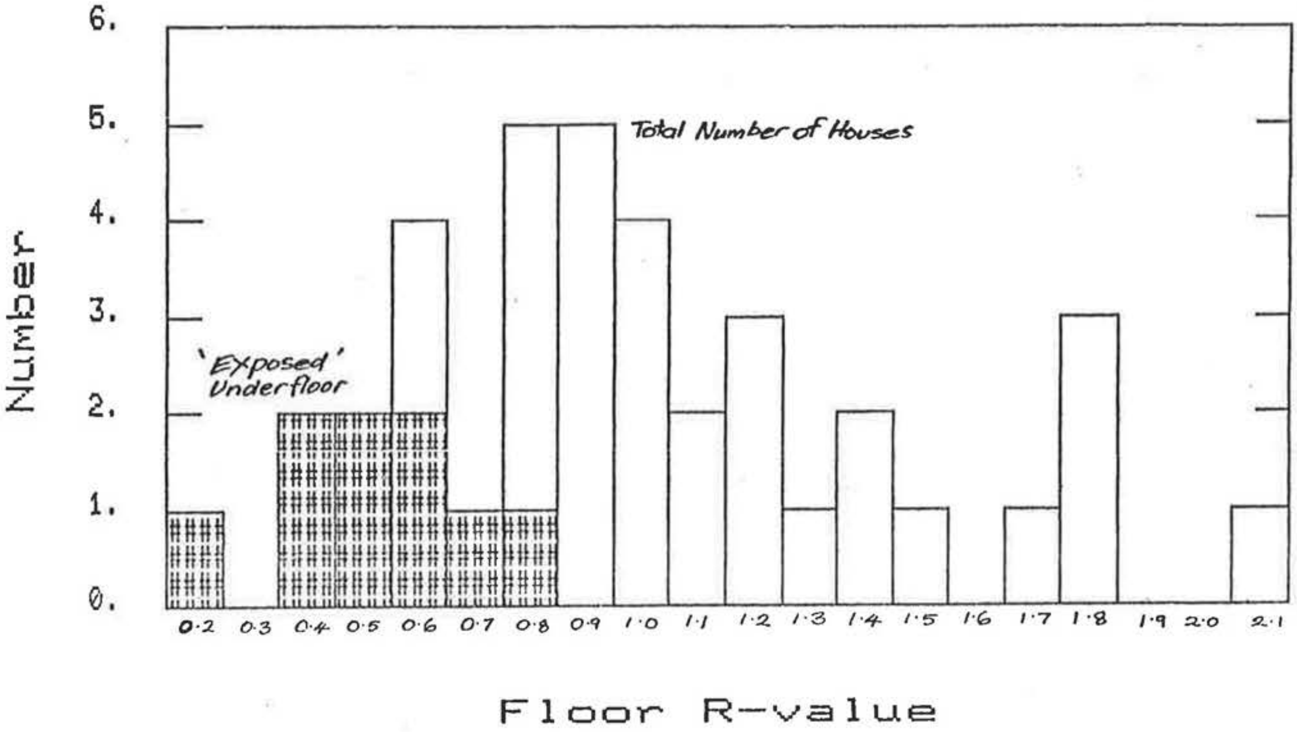

Figure 13: Floor R-values measured for suspended floors.

APPENDIX I : MEASUREMENT EQUIPMENT

DATA LOGGERS

Specifications

8 channel microprocessor controlled data loggers
8 bit Analogue - to - digital conversion

Amplifiers:	Low gain 0-255 mV full scale High gain -2.5 to +2.5 mV (centre zero)
Sampling rate:	10 selectable rates between 1024 and 1 per hour on a binary scale.
Sampling technique:	The 8 channels are read over a period of approximately $\frac{1}{2}$ second with inputs shorted. They are immediately rescanned with input connected. Each "reading" is the mean of 16 readings taken over exactly 20 mS (50 Hz power supply).

Data Storage

Standard audio compact-cassette - "PHILIPS" brand C60 Premium
Digital output recorded as ASCII character string in NRZ data-logger format.

SENSORS

Integrated Circuit Temperature Transducers)
)
National Semiconductor transducer LM 3911) (Not used for R-value
Resolution 0.1°C/mV)
Mounted inside the heat flux sensors.)

Thermocouple Temperature Difference

Copper-constantan (Type T) soldered thermocouples. (approx 40 micro V/°C)
Inside - mounted on wallside face of HFS,
Outside - attached with masking tape.

Heat Flux Sensors

600 mm by 450 mm
10 pair thermopile mounted on 16 gauge polished aluminium sheets, separated by 3 mm balsa wood spacers on four edges, and internally spacer supported
Individually calibrated
Sensitivity (approximate) 25 W/m².mV
Surface-to-surface R value (approximate) (0.1) m².°C/W
Thickness (approximate) 5mm

Edge taped with white Scotch brand tape No. 471
One outside surface with flat matt white acrylic
Other outside surface with etch primer

Held against wall with weight-load stand
Held against ceiling with spring loaded stand
Held on floor by gravity

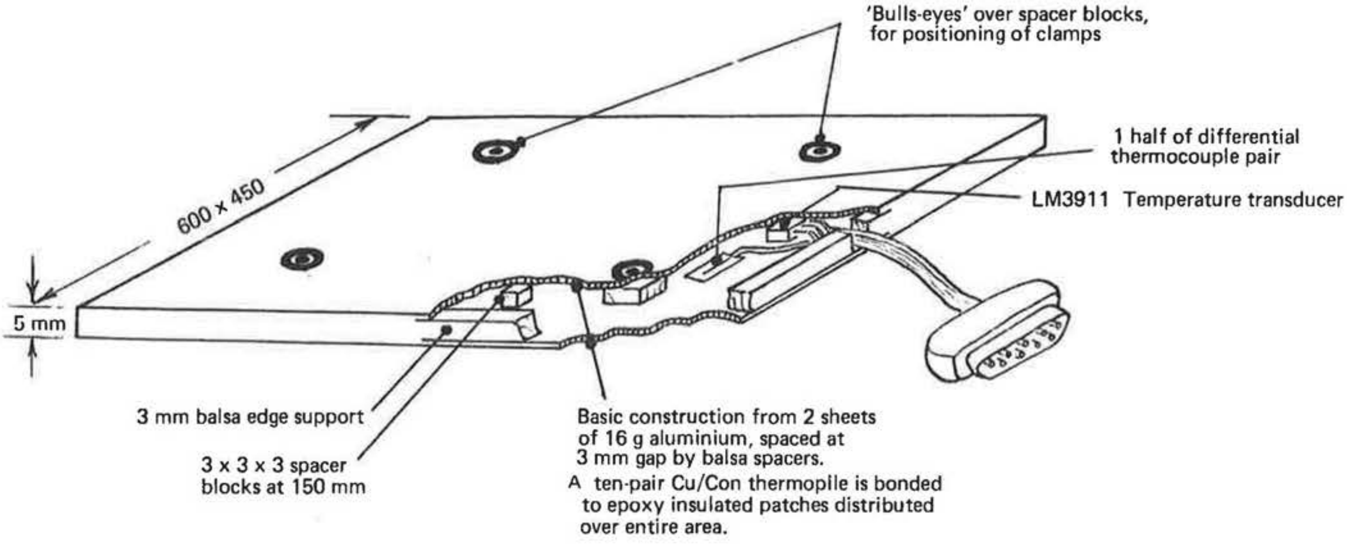

Figure 14: Cut-through view of heat flux sensor